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STUDY OF OPTIMUM ENVIRONMENTAL PROTECTION AGAINST METEOROID PENETRATION

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SUMMARY

1. SUMMARY

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A series of tests were conducted to evaluate the level of oxidative energy release produced by hypervelocity, or near meteoritic velocity particle penetration of simulated spacecraft crew compartments. Tests were performed at five different atmospheric compositions. The closed chamber used, provided a reasonable simulation of a manned module of a spacecraft. The purpose of the tests was to study the oxidative energy release which can be expected to occur with meteoroid penetration of the module or a full pressure suit and the effects produced on the space crew. One of the objectives of the study was to determine which of the given gaseous environments produced the greatest attenuation of the oxidative phenomena. Glass particles, with diameters between 250 and 1200 microns, accelerated to velocities up to 37,000 ft/sec were used in these tests. Both live animal specimens and comprehensive instrumentation were used to determine the energy release of the particle penetration of the aluminum target plates. The tests were conducted in Vought's dual-chamber hypervelocity particle accelerator. Biological effects were established by gross examination of the test specimen immediately after test exposure and by both gross and microscopic examination at autopsy.

Energy release was found to vary directly with the concentration of oxygen in the atmosphere established in the test chamber. A test survey was conducted in which a wide range of particle sizes were used to penetrate three different target thicknesses. The effect of energy release on the animal specimens was recorded at the various atmospheres. It was found

that the size of penetration is more important than the oxygen concentration in producing high energy levels. Injuries recorded varied from uniform specimen burning to temporary flashblindness.

INTRODUCTION

2. INTRODUCTION

The recorded incidence of meteoroid impacts on the relatively small payloads thus far sent into space provides evidence that manned spacecraft can be expected to have similar collisions. Studies of meteoroid flux, mass, density, and velocity have been underway for several years. More recently a study has been completed (Reference 1) in which the characteristics of effective meteoroid shielding were investigated. The test series described herein relates to an investigation of the effects on crews upon meteoroid penetration of the manned modules of spacecraft.

Violent rates of energy release associated with hypervelocity impact have been under study for many years. This type of investigation however, was undertaken in connection with space vehicles only during the last three years. During a series of such tests, conducted by Vought Astronautics scientists, it was found that high levels of heat and light energy were released in enclosed chambers behind the target plate upon penetration by hypervelocity particles. The particles used in the tests had a velocity of approximately 25,000 ft/sec. Based on these findings, Gell, Thompson, and Stembridge (References 2 and 5) conducted a series of tests to determine the effects of the energy release on animal specimens. The animals, large white rats, were incarcerated for these tests in a small pressure chamber, one wall of which was formed by a 0.070 inch thick aluminum target plate. The hypervelocity particles, accelerated by a shaped charge, penetrated the aluminum target. When the chamber atmosphere was at a 100 per cent concentration of oxygen, the penetration caused a deep uniform burning of the specimen. Even when air was used in the chamber, penetration produced shock and widespread superficial wounds in

the animal from spalled wall materials. Blast pressure was thought to have caused severe spinal injury. These results pointed up the need for an investigation of the effects of meteoroid penetration into the manned modules of spacecraft or into full pressure suits to be used by space crews. This report described the results of a study designed to partially fulfill this need.

The primary objective of this study was to establish a relationship between different breathing atmospheres and the degree of injury produced in a live animal specimen as result of meteoroid penetration of the cabin. This relationship was studied using various partial pressures of oxygen in closed chambers of two different volumes. Based upon a knowledge of this relationship, it was the purpose of this study to select a physiologically acceptable atmosphere which would afford the greatest protection against meteoroid penetration.

The principle experimental variables employed were oxygen concentration and partial pressure, target thickness and penetrating particle size. Additional tests were made in which the number of penetrating particles was regulated and the flamability of the specimen was changed by removing the hair.

Eighty-five tests were conducted although not all of them provided useful data. Data obtained consists of the physical changes which occurred on target penetration and a detailed pathological examination of each animal test specimen.

APPARATUS

3.0 APPARATUS

A dual-chambered hypervelocity particle accelerator, developed by Vought's Explosive Laboratory was used in the test series. A functional diagram of the facility is shown in Figure 1 and a photograph in Figure 2. The pellet, fixed to the end of a three-phase shaped charge is accelerated through the low vacuum over a distance of ten feet. Disruption of the pellet, which occurs on detonation of the charge, produces the particles which impact on the target at the end of the chamber. The target, an aluminum plate in this test series, serves as a pressure seal between the firing chamber and the test or cabin chamber. For test purposes, the firing chamber simulates outer space and the cabin chamber simulates a manned module of a space vehicle, and the target plate, a replaceable section of this module wall.

Target plate thickness and pellet characteristics were varied as part of the experimental design. Both the pellet material and target plate are discussed as experimental variables in the METHODS section of this report.

The firing chamber was evacuated to a pressure of approximately 4 microns of Hg pressure during acceleration so as to reduce air-resistance to particle travel. The vacuum pressure also served other purposes which are described later in this report.

A separate vacuum pumping system was provided for each of the two chambers. Using a system of valves and an external supply of oxygen, the gaseous environment of the cabin chamber was established as required for each test.

Instrumentation transducers for measurement of light intensity, velocity, blast pressure and cabin pressure, were located inside the cabin chamber. A detailed description of the instrumentation is provided in

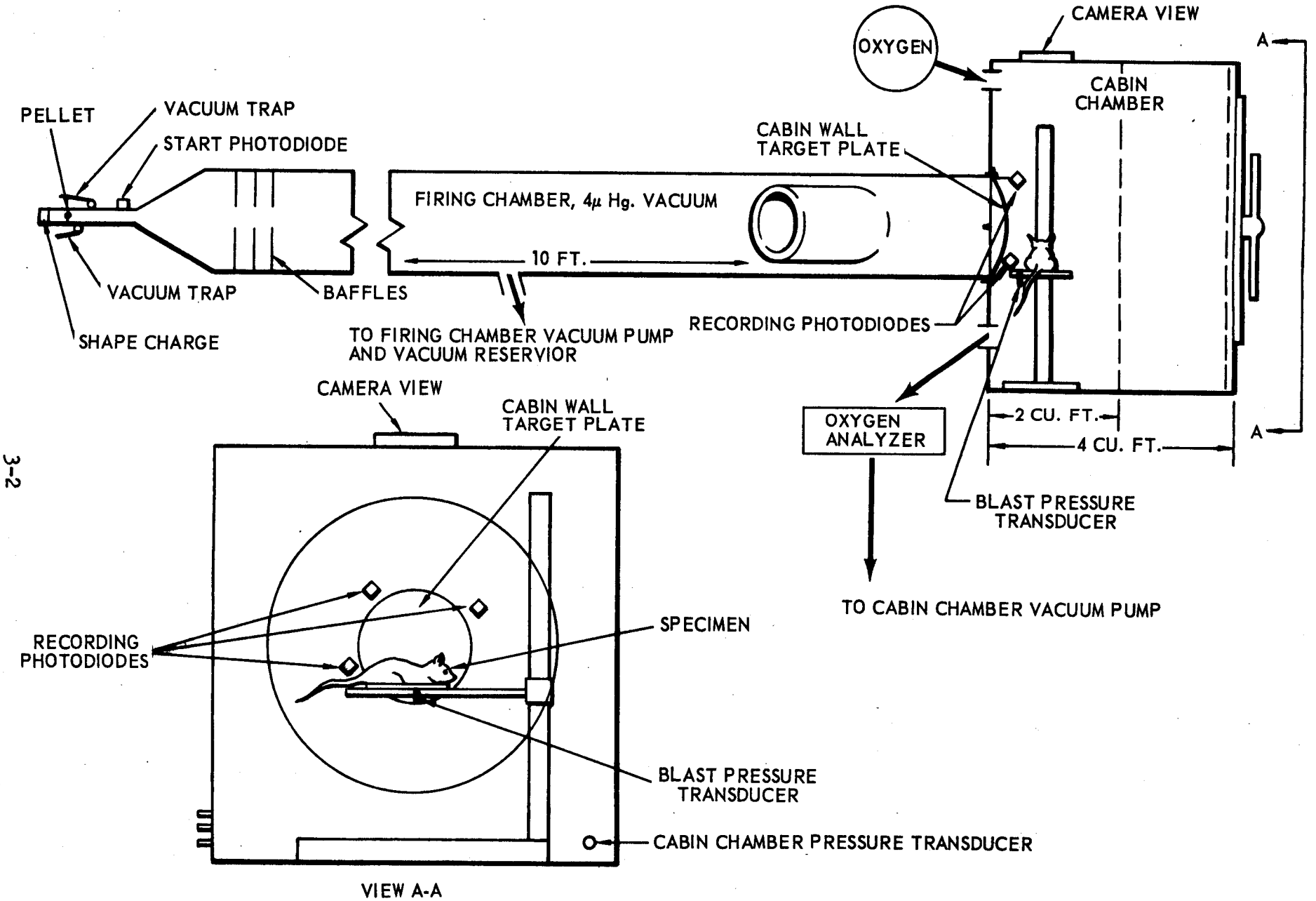
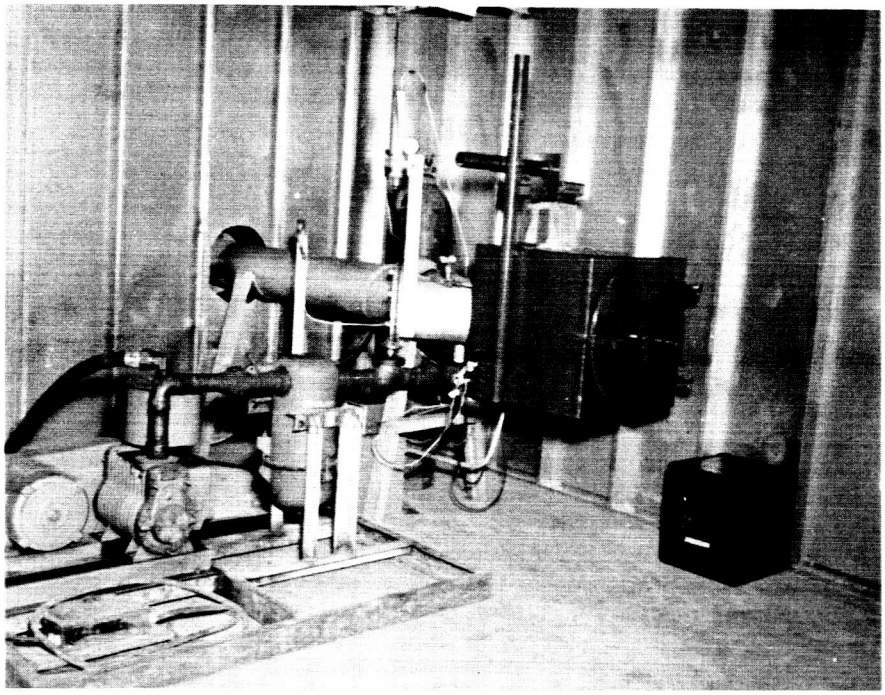
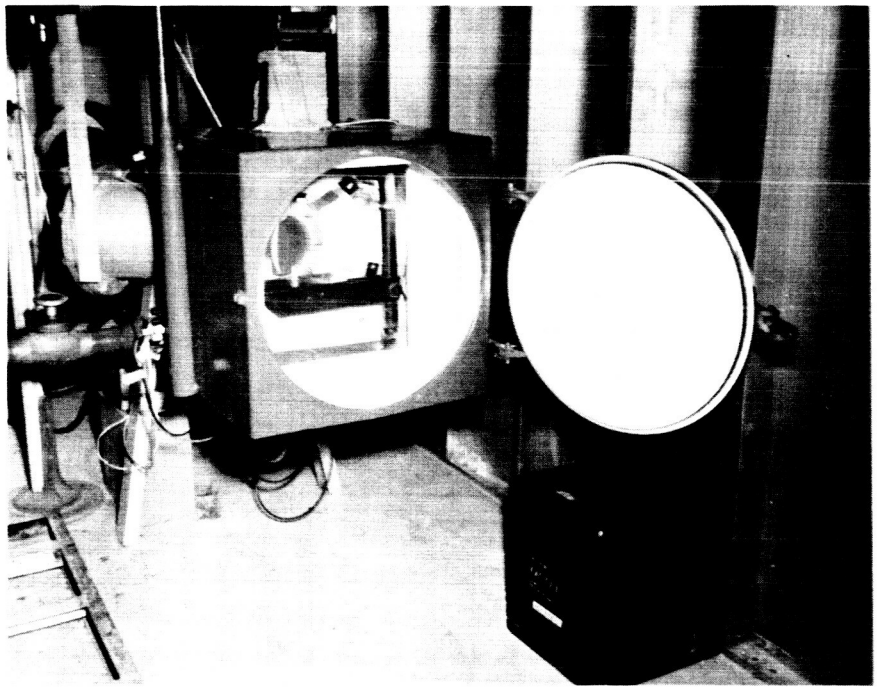


FIGURE 1. METEOROID PENETRATION STUDY APPARATUS



VIEW SHOWING ARRANGEMENT OF APPARATUS



VIEW LOOKING INTO CABIN TEST CHAMBER

FIGURE 2. TEST FACILITY

Appendix "A" of this report. The test specimen was placed upon an adjustable platform which could be located as desired inside this chamber.

3.1 Shaped Charge Design

An illustration of the shaped charge is shown in Figure 3. As indicated in the illustration, the charge is pressed onto an aluminum base. The base has provisions for the detonator cap, a small booster charge, and has a groove for an "O" ring. The layers appear in the following order from the base to the pellet. The first layer is RDX pressed at 25,000 psi pressure. This is followed by a layer of inert material which serves as a barrier to divert the detonation front and to cause it to reconverge in an amplified manner behind the pellet. The explosive behind the pellet is a pressed (40,000 psi) layer of RDX. The RDX used was manufactured by the Olin Corporation. It contained 2.5 percent wax.

Design of the shaped charge was essentially an empirical process. Trade-off considerations involved primarily the direction of a sufficient amount of the blast wave in the proper direction with the desired frontal area. Practical limits exist on the amount of explosive which can be used.

The shaped charge is not inserted directly into the firing chamber. It is first sealed to a 16 inch long aluminum tube which is in turn sealed into the firing chamber. This technique permits all but the forward directed explosive force and gases to be dissipated outside the chamber.

3.2 Firing Chamber Pressure Regulation

Contamination of the cabin chamber was reduced by maintaining a pressure inside the firing chamber which was negative to the test chamber. Gas flow from the penetrations was thus always toward the firing chamber as would be the case in the space environment.

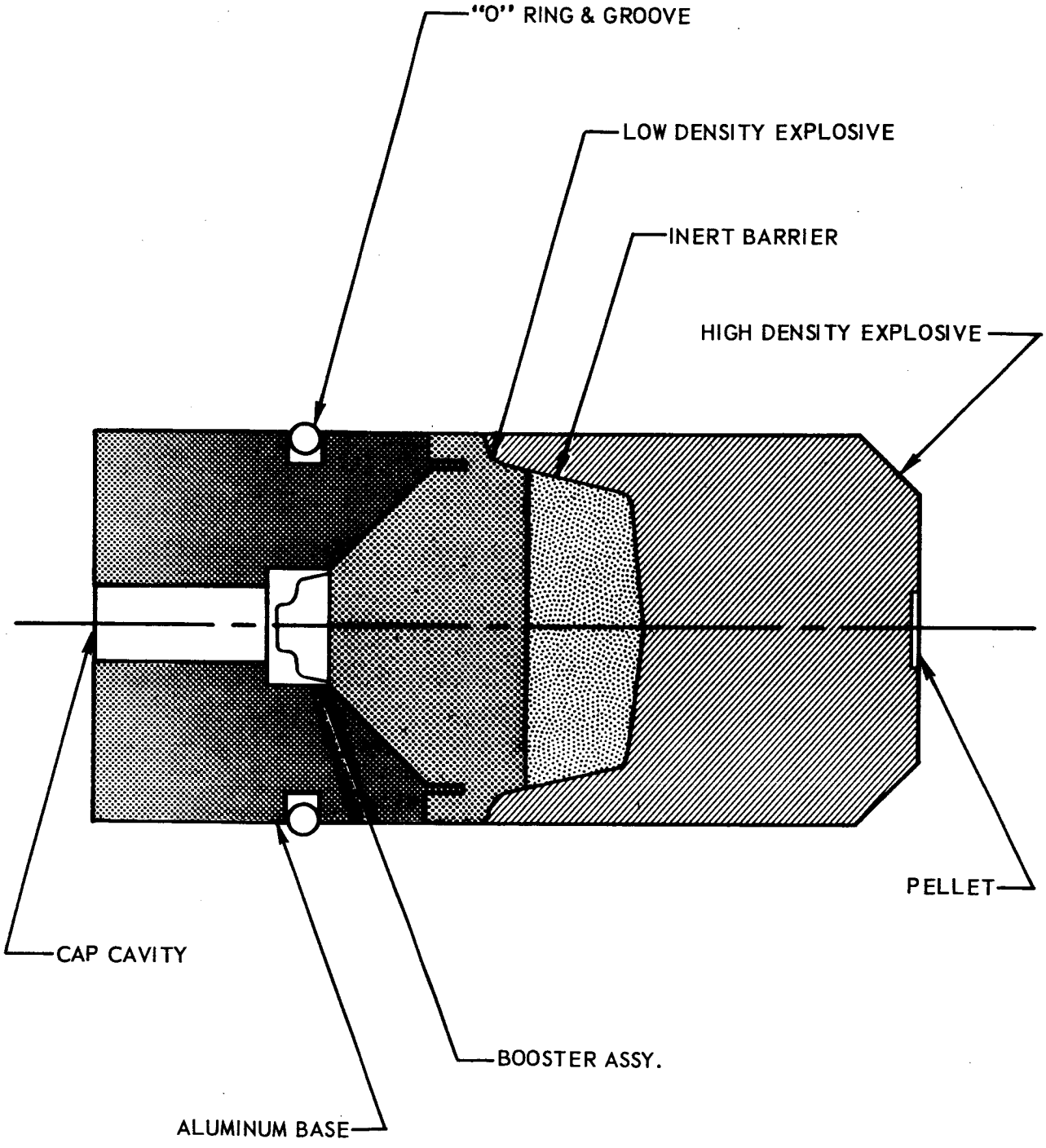


FIGURE 3. TYPE 15 – .250 SHAPED CHARGE USED TO ACCELERATE PELLETS TO HYPERVELOCITIES

3.2.1 Sealing Device

In order to maintain the vacuum pressure of the firing chamber throughout the test, a crimping device was employed to seal the opening caused by the detonation of the charge. This device was located in front of the opening provided for insertion of the aluminum tube housing the shaped charge. The device, activated by the vertical components of the shaped charge blast wave, causes a pair of offset rollers to close from opposite directions on the aluminum tube extending ahead of the shaped charge. The aluminum tube used is sufficiently ductile thus permitting a seal to be formed without shearing.

3.2.2 Baffle System

A series of baffles were provided inside the firing chamber to disrupt the blast wave and prevent the expanding gases from entering the test chamber. The series of baffles had an orifice diameter gradient which effectively restricts the flow of gases into the firing chamber, setting up a turbulence which is partially directed back into the incoming stream. The pellets immediately ahead of the shock wave are not disturbed in their trajectory toward the target. Although the volume of gases which entered the chamber was not reduced, the velocity of flow is greatly decreased, as shown by the lack of damage to the target plate when a charge without a pellet was fired.

3.2.3 Vacuum Pressure Reservoir

To insure an adequate compensation for the gases which entered the firing chamber, provisions were made for the vacuum of the chamber itself to be augmented by another larger interconnected chamber maintained at the same pressure.

3.3 Cabin or Test Chamber Configuration

Tests were conducted in two volume configurations of this chamber so as to permit any influence which the metabolic processes of the animal might have on the oxidative energy release level to be identified. One configuration had a volume of 2 cubic feet while the second was 4 cubic feet. These volumes were easily changed by removal of a rectangular section from the test chamber.

The chamber consisted of three sections. The first section, which contains the door, has a volume of 0.5 cu. ft. It is attached to the second by a series of bolts. The second section has a volume of 2 cu. ft. and was in turn attached to the third section by another series of bolts. The third section, which has a volume of 1.5 cu. ft., contained the necessary provisions for target mounting, instrumentation connections and atmospheric control. Obtaining a 2 cu. ft. chamber is accomplished by removing the second section from the assembly.

3.3.1 Instrumentation Transducer Location

As can be seen in Figure 1, the photodiodes, blast pressure pickup, and thermocouple are located near the target plate. The cabin pressure sensor is also located at the bottom of this section of the test chamber.

The three photodiodes, with associated filters, are mounted on arms extending out from an aluminum collar. This collar also fastened the target in place. The arms are bent to enable each of the photodiodes to "see" overlapping areas of the target. Reasonably good target coverage was obtained in this manner.

The thermocouple was fabricated with a magnetic mounting device that allowed free selection of location for each test shot. The most frequent location was just below the center of the animal. Since little or no useful

data was obtained from this transducer, no record was made of the few exceptions to this general location. Further details are provided in Appendix B describing the instrumentation. Briefly, the cause of failure to obtain good data is a result of the very transitory nature of the heat produced by target penetration and the limited response rate of the faster temperature measuring devices in gas.

The blast pressure pickup was located out of the line of sight of the particle stream on the specimen platform. The transducer which was used is similar to the one recommended by the Lovelace Foundation in their blast effect studies. Greater detail is given in Appendix B. The piezoelectric transducer faced upward just in front of the animal and normal to the pellet stream. The surface of the transducer was almost flush with the surface of the platform to protect it from particle impact.

All electrical connections were made through a pressure sealed terminal block located in the side of the test chamber.

3.4 Target Plates Selection and Characteristics

Three thicknesses of target plate material were used. Material selection was based upon structural analysis conducted in connection with various proposed single-walled man modules for non-reentry type spacecraft or protective shields for space workers. The thicknesses employed in this test were of 0.016 inch, 0.020 inch, and 0.064 inch.

The two thicker targets were of 5052SO aluminum while the 0.016 inch target was 7075-ST ALCLAD. All of the 0.016 inch thick targets used were flat plates while the other two target thicknesses were formed into partial hemispheres with a radius of approximately 2.5 inches. None of the targets were heat treated.

The hemispherical configured targets were used to investigate the possibility that the angle of particle impact and penetration would effect the energy release behind the target. No such indication was found in this test series but the target configuration was retained to ensure uniformity of test conditions.

Target thickness did affect the selection of particle or pellet size used in the test. The 250 micron or 60 grit silicon carbide particles did not have sufficient energy on impact to clearly penetrate the two thicker targets. Some penetrations did occur but so little energy was left after the cratering and penetration of the plate that the effects noted in the test chamber were negligible.

This was also the case, to a degree, when the particles resulting from acceleration of the 0.1 in diameter glass pellet were used with the 0.020 inch target. Much less material was displaced and less energy released simply because there was less particle material available or it was divided into particles too small to produce penetration under any circumstance.

This information relates to the selection of target plate only because it was desired to select a target which would be representative of spacecraft walls. These walls would tend to be thicker than 0.016 inch. When the glass pellet technique was discovered, a thicker, more representative aluminum plate was used.

The thicker targets each produced a characteristic energy release test condition. This results principally from the larger energy release behind the target which varies as a function of several parameters such as particle mass and velocity.

It would do well to note in viewing the results that even smaller particles than those used here traveling at higher velocities could penetrate any of the wall materials used.

3.5 Pellet Selection and Characteristics

Refractory materials as similar as possible to recovered meteoroids were used to produce the particles for these tests. Earlier attempts to accelerate silicon carbide and glass had been unsuccessful in this facility because of the brittle characteristics of these compounds. The shock wave produced by detonation of the shaped charge reduced this material to such fine particles that only erosion craters occurred in the target. Epoxy resin was included, primarily by intuition, among the fixative material evaluated as possible shock absorbers and holding agents for the pellets. This resin proved very successful in every respect, holding the pellet together long enough to permit acceleration without complete shattering yet vaporizing sufficiently before reaching the target to prevent cratering.

Epon 828, a Dow Chemical epoxy resin, was used throughout the study to hold the pellet in place whether it was in grit form or in a single piece. The few particles of pellet recovered were found, under microscopic examination to be free of epoxy. It was found in early tests using 60 grit silicon carbide particles accelerated to velocities greater than 24,000 ft/sec that few hypervelocity penetrations were produced in the thicker targets. To obtain the test condition provided by penetration of the thicker plates, glass pellets were adopted. The use of glass pellets produced particles which gave larger penetrations as well as faster ones. Both add to the energy release behind the target.

The glass pellet used was ground out of Corning Glass Company microscopic slide cover-slip, Number 1. This glass sheet is 0.054 inches thick. The pellets were cut with a piece of tubing in a drill press using valve grinding compound as an abrasive. Silicon carbide grit was bought in bulk from the Carborundum Co. Pellet mass was as follows: Individual particles of 60 grit, 9×10^{-5} gms.; 0.10 glass, 0.0017 gms.; and 0.24 glass, 0.009 gms.

Apparently the shaped charge detonation changes the state of the glass pellet into a molten or plastic form. This observation is based on the appearance of the impact craters in the target. The significance of this particle state on the test results is not clear. Hypervelocity particles are known to "see" the structure of the target material as a fluid. The impacting particle also becomes fluid at impact. (Reference 2). Microscopic appearance of the exit side of the penetration produced by silicon carbide particles is not significantly different from that the of glass. The energy released behind the target is the same for a particular particle mass at an equal velocity. The crystalline structure of silicon carbide is small and does not permit explosive acceleration in large particle form without breakup. The larger particles, even when mounted in epoxy resin, immediately break up to approximately the 60 grit size or smaller, and therefore were not accelerated up to the 30,000 ft/sec velocity range needed for the most useful test. Through inquiries made of the Carborundum Company, it was learned that a recrystalized form of silicon carbide was under development. This material, available in April, 1963, may eliminate this test consideration.

A small depression was made in the face of each shaped charge during pressing to accomodate the pellet. A droplet of resin, approximately 0.02cc was applied to the bottom of the depression with a fine wire. The glass pellets were then dropped into place. The silicon carbide grit was placed in the depression and covered with another droplet of epoxy of the similar volume. Curing time provided was 24 hours minimum.

Some variation will be seen in the glass pellet diameters used. The grinding technique described on the previous page had approximately 0.01 inch tolerance.

3.6 Animal Specimens

The white rats used as test specimens were obtained from the stock of Sprogue-Darnley strain maintained at the Southwestern Medical School. Their weight was approximately 300 grams. Variations from this weight ranged as much as 50 grams however.

Environmental control in the animal holding area at the test facility was poor. Although an effort was made to keep the holding time in that location to a minimum, some animals were exposed to marked temperature and humidity changes for as long as 15 days.

Animals were sacrificed within hours of the test in which they were used. When prolonged stress was anticipated, Nebutal was administered intermuscularly.

PROCEDURE

4.0 PROCEDURE

The only difference in the method of preparing the apparatus for the various test conditions was that used in establishing the gaseous atmosphere. The general procedure will therefore be described, to be followed by such deviations in the procedures as are necessary.

4.1 Preparation of the Firing Chamber

The firing chamber was maintained under vacuum as much of the time as possible to avoid prolonged pump-down time resulting from outgassing of chamber materials. After each test, the baffles were quickly observed for obstructions and the shaped charge and holding tube inserted for the next shot. As soon as the target used in the previous test was replaced, pump-down was started.

The shaped charge design provides an "O" ring which seals it in the aluminum tube. The aluminum tube is in turn sealed into the firing chamber for the next test by another "O" ring. A flat gasket of rubberized nylon is used under the targets. Vacuum pressure is measured using a McLeod Gage. Pumping was continuous until just before the next test when a valve in the suction line was closed to prevent contamination of the pump with combustion products.

4.2 Preparation of the Test Chamber

Accurate light intensity recordings required the use of appropriate filters to control the amount of light in the visible spectrum, that reached the photodiode. Filters that eliminate all the ultra-violet and infra-red light were used to cover the photodiodes throughout the tests. It was found, however, that more light was produced than could be handled by the

instrumentation photodiode circuits; consequently visible light filters had to be used to control the light reaching the diodes. The first step in preparing the cabin chamber for each test was to verify the light filter arrangement for the test condition anticipated. More or less filter layers were applied as required. Additional information is given in Appendix B including a figure of a typical Memoscope recording. Functioning of the other transducers was then verified and the test chamber temperature recorded. Following the instrumentation checkout, the camera selected for the shot was put into place, focused, and loaded. When "open shutter" polaroid camera was used to record energy release, it was opened immediately before the test and closed immediately afterward to avoid film exposure from extraneous light. Activation of the Fastex camera, on the other hand, was sequenced with the shaped charge detonations. A timer programmed the starting of the Fastex camera, the oscillograph, and fired the charge, in the proper sequence.

The animal was fastened on a mounting fixture with fine steel wire, thus restraining it in a normal upright position. When the test apparatus was prepared, the animal and fixture were placed on the platform. A small "C" clamp was used to hold it in place. Adjustment of the platform was then established according to the protocol. Thumb-screw locks were provided for this purpose. The thermocouple was placed against the platform approximately 1 inch below and in front of the specimen's abdomen. The The chamber door was then closed and sealed into place.

4.3 Establishing The Atmosphere

Except for tests under ambient atmospheric conditions, oxygen was flooded into the cabin chamber immediately after the door was sealed.

The cabin chamber vacuum pump was then started. Pumping pressure was varied by bleeding air into the vacuum line between the pump and chamber. This arrangement also prevented dangerous concentration of oxygen from reaching the pump. The bleed valve was located just ahead of the pump inlet. The oxygen was allowed to dilute the air in the chamber under a slight negative pressure until 100 per cent oxygen was recorded on the D-2 oxygen Analyzer. The analyzer was located in a parallel system to the pump suction-line. Valves were employed to provide zero flow readings at chamber pressure, and isolation at the time of firing. When 100 per cent oxygen concentration was achieved, oxygen flow was stopped and the vacuum pressure allowed to increase to the test pressure scheduled.

When the 50 per cent oxygen--50 percent nitrogen atmosphere at 7 psi was required, the procedure was somewhat altered. In this case the oxygen was allowed to flow into the chamber until the proper concentration was established. Pressure was then decreased to 7 psi and the oxygen content rechecked. Minor adjustments were then made if necessary by adding air or oxygen as required.

4.4 Specimen and Data Recovery

Immediately after the test the Memoscope traces were photographed with a special polaroid camera and the exposed film removed from the test chamber. The oscillograph data sheet was equipped with an automatic marking feature thus requiring no immediate attention. The rolls of recording paper were changed as required.

Specimen removal was then undertaken. The animal was brought into an adjoining room for examination. Immediate tests were conducted to determine auditory and visual functioning.

Auditory function was first checked by snapping the fingers behind the animal. If no response was obtained, the tail was thumped to determine if tactical response was present. Visual examination was performed by moving an object quickly toward the face of the specimen. When no response was obtained, a soft blunt object was moved in until the cornea was touched, removed, and then moved in again. A blink reflex prior to touch was sought as a positive indication. The degree of disoreintation was observed simply by watching the animal move about among other objects on a table top.

When this examination was completed, the animal was taken to the Southwestern Medical School for autopsy. Heavy burning normally resulted in death in a short time. If this did not occur, the animal was sacrificed.

RESULTS

5.0. RESULTS

This test series was aimed primarily at evaluating the relative injurious effects produced in the animal test specimen by oxidative explosions under five test atmospheric conditions. It became apparent early in the study that the size of the penetrating particles significantly affected the energy release level produced in the oxidative energy release and therefore the degree of injury to the animal. Particle size cannot be readily controlled when the shaped charge acceleration technique is employed. For this reason three types of pellets, producing particles in three size ranges, were used. Varying this test parameter permitted variations to be made in target thickness. In some cases the number of replicates in each individual condition was reduced by introducing these variables. The total number of tests was generally fixed by the contractual scope of the study. Results are reported in this section under the general heading of the gaseous environment employed in the test chamber and are further broken down according to target thickness and particle size. There are also two separate headings for certain special test conditions. A data summary follows each discussion of tests under a given atmospheric condition. Photographs of the target showing penetration characteristics obtained in each test are also included. The significance of the results are considered in the General Discussion of this report. A summary of all tests conducted is provided in Appendix C and complete pathology reports are given in Appendix A.

To determine the pathological effects on the animal of the manipulations required to establish the test atmosphere in the cabin chamber,

a single animal was cycled through all of the pressure and gaseous changes used in the test series. All normal pretest handling was used. This animal was then sacrificed and given a post-mortem examination. The pathological findings for injury were negative. This specimen is termed the pressure control in this report.

100% OXYGEN
14.7 PSI

5.1.2. 0.064 Inch Thick Hemispherical Aluminum Target Wall

One of the three tests in this category produced grossly only singeing of the specimen's hair, temporary flash blindness and slowness in response. On this test the animal was located outside the particle stream. Pathological examination revealed an intense pulmonary edema associated with small areas of the hemorrhage in the lung. Examination of the lungs also revealed the presence of an abnormal infusion of gas into the lung tissue (emphysema) and some aluminum oxide residue (Pathology, Test No. 86). This may be an indication of blast injury. On the other two tests, the animal was located in the particle stream and both tests produced uniform burning of the most severe type. The hair was burned uniformly to the epidermis and third degree burns of the skin resulted. Lung damage included severe pulmonary edema, and congestion. (Test No. 87 and 89). These data are summarized on Table 1.

5.1. 100 Percent Oxygen - 14.7 P.S.I.A.

Fifteen tests were conducted at ambient atmospheric pressure with 100 percent oxygen. Ten of these tests were conducted in the 4 cu. ft. chamber and five in the 2 cu. ft. chamber. Only the 4 cu. ft. group will be discussed here. This particular concentration of oxygen was used as a control condition to check the results of a previous series of tests in which no gross pathological effect was found. In terms of cabin atmospheric hazard it was the worst possible condition.

5.1.1. 0.016 Inch Thick Aluminum Target Wall

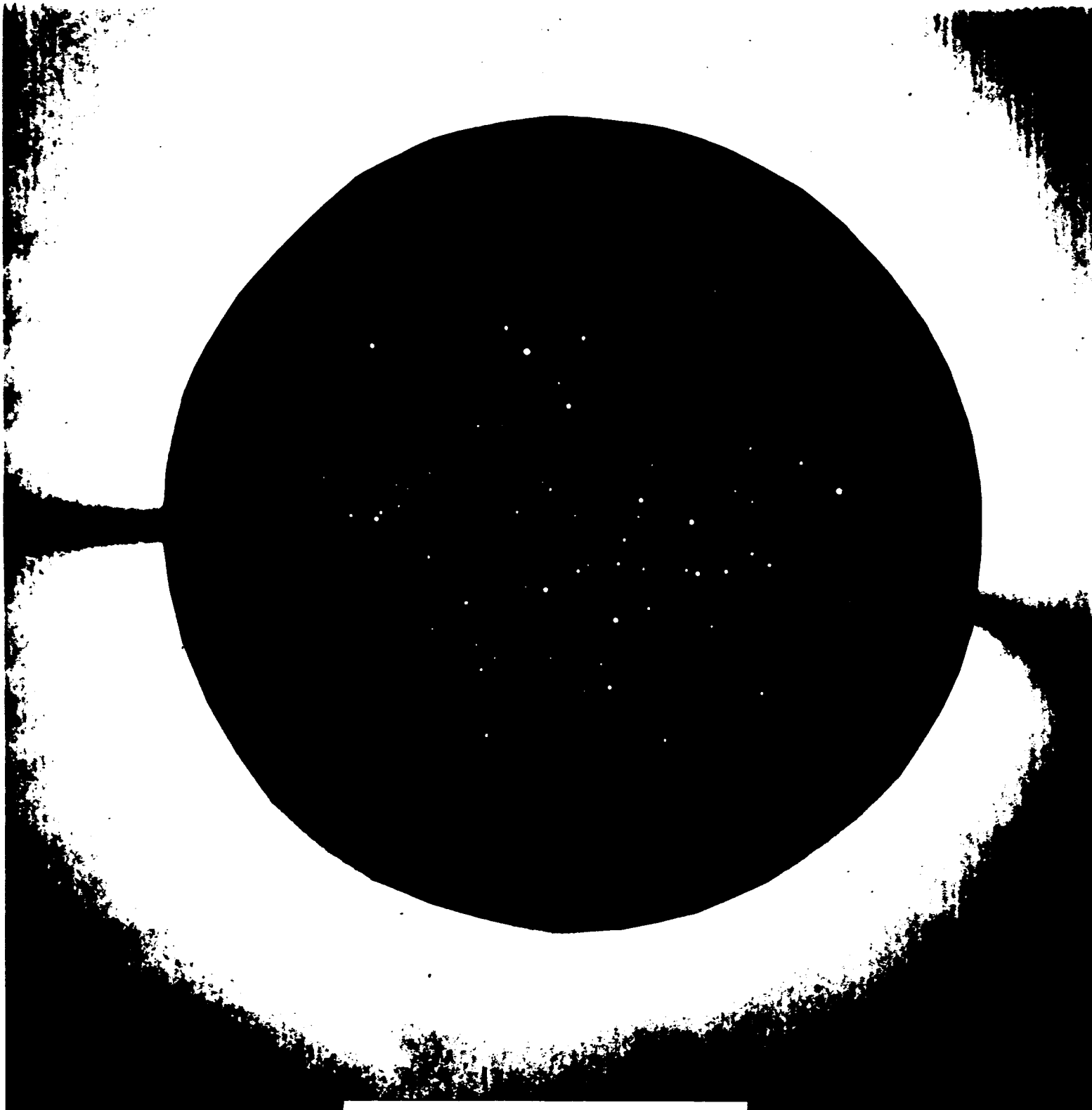
Seven tests were conducted at this oxygen concentration and pressure using the thin, flat target wall. Sixty grit (9×10^{-5} gm.), silicon carbide (test No. 80), 0.1 inch diameter glass (0.0017 gm.) (test no. 83), and 0.24 inch diameter (0.009 gm.) glass (test no. 84) were used as pellets. These varied pellet sizes produced the full range of the penetrating particle sizes and velocities used in the test series. When the test specimen was not located in the particle stream, it was not burned. The particle stream is best defined as the area of light stream shown in Figure 7. Pathological examination indicated only deposition of aluminum oxide particles on the hair and some singeing. Moderate broncho pneumonia was found to have produced intense congestion of the vessels in the lungs of these test specimens (Pathology, Test No. 84). This lung condition, however, cannot be demonstrated to result solely from the test experience. It should be noted that in subsequent tests, when the specimen was located in the area of energy release, and the same oxygen concentration and target are used, the specimen did burn when the target was penetrated by the larger two pellets. This was found to be true at the 5 psia 100 percent oxygen condition also.

TABLE I

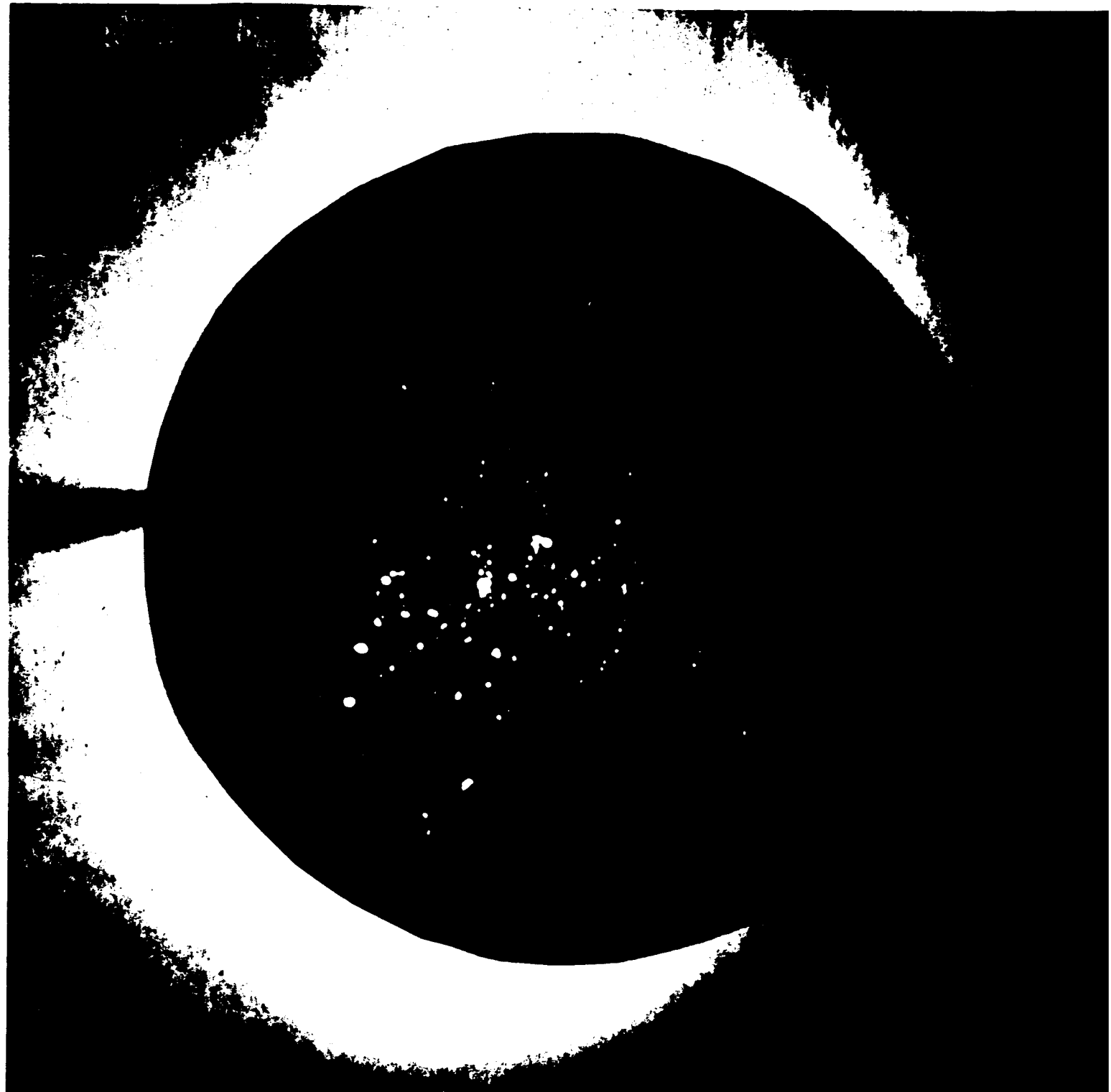
Test Data At 100 Percent Oxygen - 14.7 PSIA Chamber Atmosphere

TEST NO.	PELLET	VELOCITY FT/SEC.	LIGHT FT. CILS.	BLAST OVER-DRESS	GROSS EFFECT
.016 Inch Thick Target Wall					
78 *	.1 Inch Dia. Glass	27, 900	1500	5 PSI	No Burning
79 *	.1 Inch Dia. Glass	28,500	1500	3 PSI	No Burning
.016 Inch Thick Target Wall					
80	#60 Silicon Carbide	21,700	3000	2 PSI	No Burning
81	.1 Inch Dia. Glass	31,300	3000	No Data	No Burning
83	.1 Inch Dia. Glass	31,200	7500	3 PSI	No Burning
84	.24 Inch Dia. Glass	30,000	7500	10 PSI	No Burning
85	.24 Inch Dia. Glass	29,400	22,500	10 PSI	No Burning
.064 Inch Thick Target Wall					
86	.24 Inch Dia. Glass	30,200	7500	2 PSI	No Burning
87 *	.24 Inch Dia. Glass	30,200	No Data	13 PSI	Burned
89 *	.24 Inch Dia. Glass	30,700	50,000	7 PSI	Burned

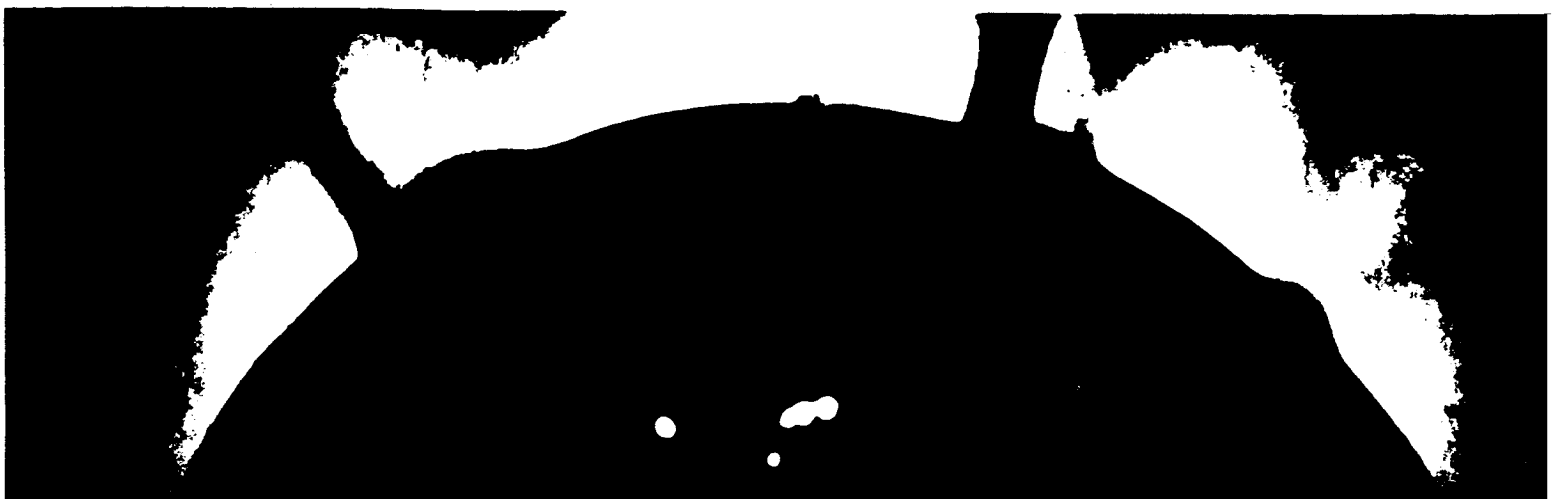
* Animals located in particle stream



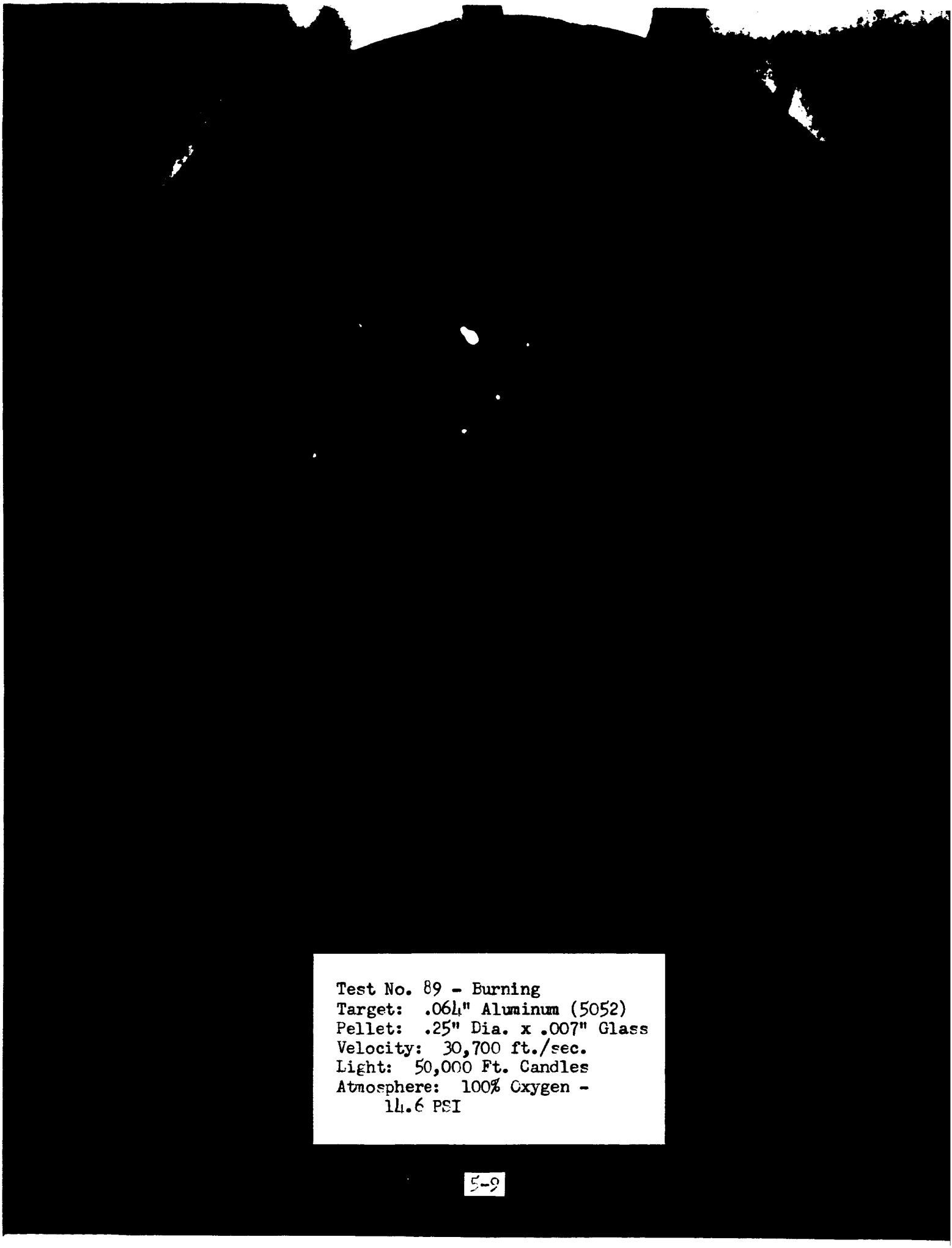
Test No. 80 - No Burning
Target: .016" Aluminum (7075)
Pellet: #60 SiC
Velocity: 21,700 ft./sec.
Light: 3,000 Ft. Candles
Atmosphere: 100% Oxygen -
14.6 PSI



Test No. 84 - No Burning
Target: .016" Aluminum (7075)
Pellet: .25" Dia. x .007" Glass
Velocity: 30,000 ft./sec.
Light: 7,500 Ft. Candles
Atmosphere: 100% Oxygen -
14.6 PSI



Test No. 86 - No Burning
Target: .064" Aluminum (5052)
Pellet: .25" Dia. x .007" Thick
Velocity: 30,200 ft./sec.
Light: 7,500 Ft. Candles
Atmosphere: 100% Oxygen -
14.6 PSI



Test No. 89 - Burning
Target: .064" Aluminum (5052)
Pellet: .25" Dia. x .007" Glass
Velocity: 30,700 ft./sec.
Light: 50,000 Ft. Candles
Atmosphere: 100% Oxygen -
14.6 PSI

100% OXYGEN
5 PSI

5.2. 100 percent oxygen - 5 P.S.I.A.

There were 39 tests conducted at this "key" atmospheric condition. Twenty-three of these tests involved special conditions which, for this reason, are reported under a separate sub-heading. Again, all target thicknesses and pellet sizes were employed. All but one test described here was performed in the 4 cu. ft. test chamber. The other tests at this atmosphere, described in paragraph 5.6.2 were made in the 2 cu. ft. chamber.

5.2.1. 0.016 Inch Thick Aluminum Target Wall

Four tests were made using 60 grit silicon carbide pellets. These tests, which preceded the 100% oxygen - 14.7 psia tests, did not have the animal in the line of fire. There was no significant pathology on these tests, although a loss of visual function was noted. When a 0.1 inch diameter glass pellet was used, (Test No. 77) under the same conditions, there was again little injury produced although greater velocity and penetrating particle size were achieved. Only small penetrations were obtained. Test No. 143 was conducted in the 2 cu. ft. test chamber using 0.24 inch diameter glass pellet. Burning occurred in this test with the animal located in the particle stream.

5.2.2. 0.020 cubic Thick Hemispherical Aluminum Target Wall

In order to determine the minimum particle size and target thickness which could produce burning at this gaseous environment, a series of five tests was conducted using 0.20 inch thick aluminum hemispherical targets and 0.1 inch diameter glass pellets. Specimen burning occurred in one case only. On this particular target (Test No. 99) six particles penetrated in an overlapping manner. The hole produced is crescent shaped and approximately 0.35 inches long and 0.025 inches wide. Uniform burning of the hair, to the

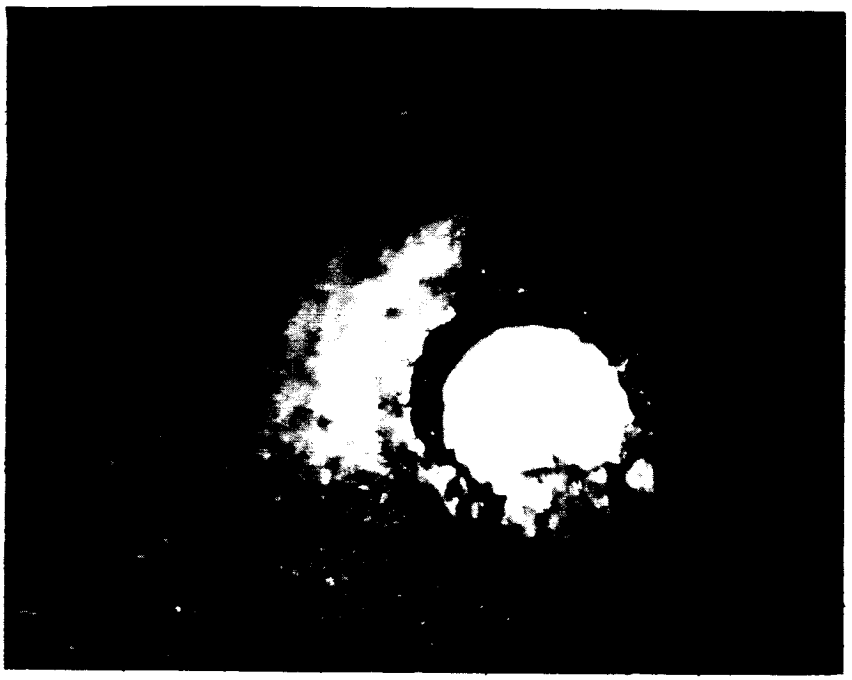
epidermis, and third degree burns of the skin were indicated by pathological examination. Edema and congestion were evident in the lung. (Pathology, Test No. 99). More widely dispersed penetrations on the other four targets did not produce ignition of the specimen. Aluminum oxide deposits were noted on the hair along with slight singeing. Intense congestion of the lungs occured. (Pathology, Test No. 102). The specimens were mildly disoriented when removed from the test chamber. Where specimen burning occurred the light intensity was 2.5 times greater than when no burning occurred.

Test No. 139 is typical of the penetrations produced by .24 inch glass pellets on this size target. Most of the special tests were conducted using this target and pellet size. Penetrations, when moderately large, produced burning at all concentrations of 100% oxygen. Pathological results were not significantly different from those found in other burned specimens at this atmospheric condition. (Refer to Paragraph 5.3). No repetitions of this test condition were made because it was determined at this point in the test series that specimen burning occurred as readily at 3.5 psia-100% oxygen when this target and pellet combination was used.

5.2.3. 0.064 Inch Thick Hemispherical Aluminum Targets

Six tests were made using 0.064 inch thick targets and the .24 inch diameter glass pellets. Four of the tests resulted in uniform and complete burning of the specimen. (Test Nos. 90 & 92). The usual pathological effects from burning were noted. In one of the tests where no burning occurred, the target was penetrated at a normal velocity of 33,400 feet per second. The light produced, however, was only 9,500 foot candles as opposed to 25,000 to 60,000 foot candles recorded on those tests in which burning did occur. The appearance of the holes produced on the back of this

target indicates that the particle energy was nearly spent in completing the penetration. The normal, clearly sheared edge of the penetration was not observed; instead, the edge of the hole formed a lip extending out toward the center of the hole, (Figure 4). Heavy spalling was also produced, causing a bleeding wound in the shoulder of the rat. This type of injury is described in the Appendix A under the Parameters of Animal Injuries and is shown in Figure 4-4.



LOW VELOCITY

HIGH VELOCITY

FIGURE 4. APPEARANCE OF HOLES PRODUCED ON EXIT FROM ALUMINUM TARGET BY TWO VELOCITIES OF GLASS PARTICLES (90X)

TABLE II

Test Data at 100 Percent Oxygen - 5.0 PSIA Chamber Atmosphere

TEST NO.	PELLET	VELOCITY FT/SEC	LIGHT FT CDLS.	BLAST OVER-PRESS	GROSS EFFECT
.016 Inch Thick Target					
73*	#60 Silicon Carbide	27,900	1,050	1 PSI	No Burning
74*	#60 Silicon Carbide	26,400	625	1 PSI	No Burning
75*	#60 Silicon Carbide	23,800	850	No Data	No Burning
76*	#60 Silicon Carbide	25,700	600	No Data	No Burning
77*	.1 Inch Dia. Glass	36,000	600	No Data	No Burning
143**	.25 Inch Dia. Glass	31,700	275,000	30 PSI	Burned
.020 Inch Thick Target					
98	.1 Inch Dia. Glass	35,800	3,700	5 PSI	No Burning
99	.1 Inch Dia. Glass	31,200	24,800	6 PSI	Burned
102	.1 Inch Dia. Glass	37,100	2,000	4 PSI	No Burning
103	.1 Inch Dia. Glass	28,700	450	No Data	No Burning
104	.1 Inch Dia. Glass	34,400	2,000	1 PSI	No Burning
139	.24 Inch Dia. Glass	34,500	60,000	23 PSI	Burned
.064 Inch Thick Target					
90	.24 Inch Dia. Glass	31,300	22,500	4 PSI	Burned
91	.24 Inch Dia. Glass	No Data	No Data	No Data	No Burning

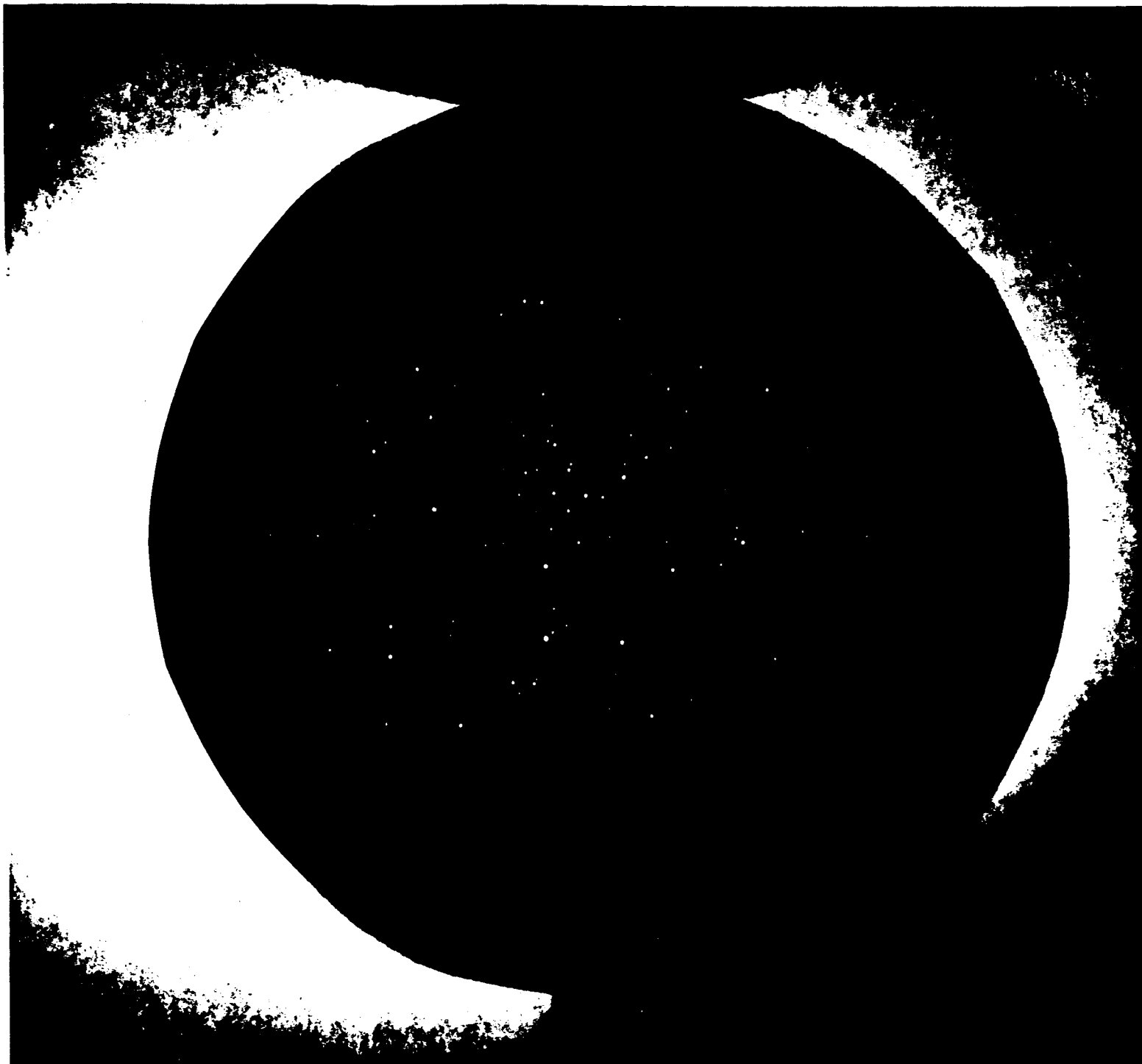
TABLE II - Continued

Test Data at 100 Percent Oxygen - 5.0 PSIA Chamber Atmosphere

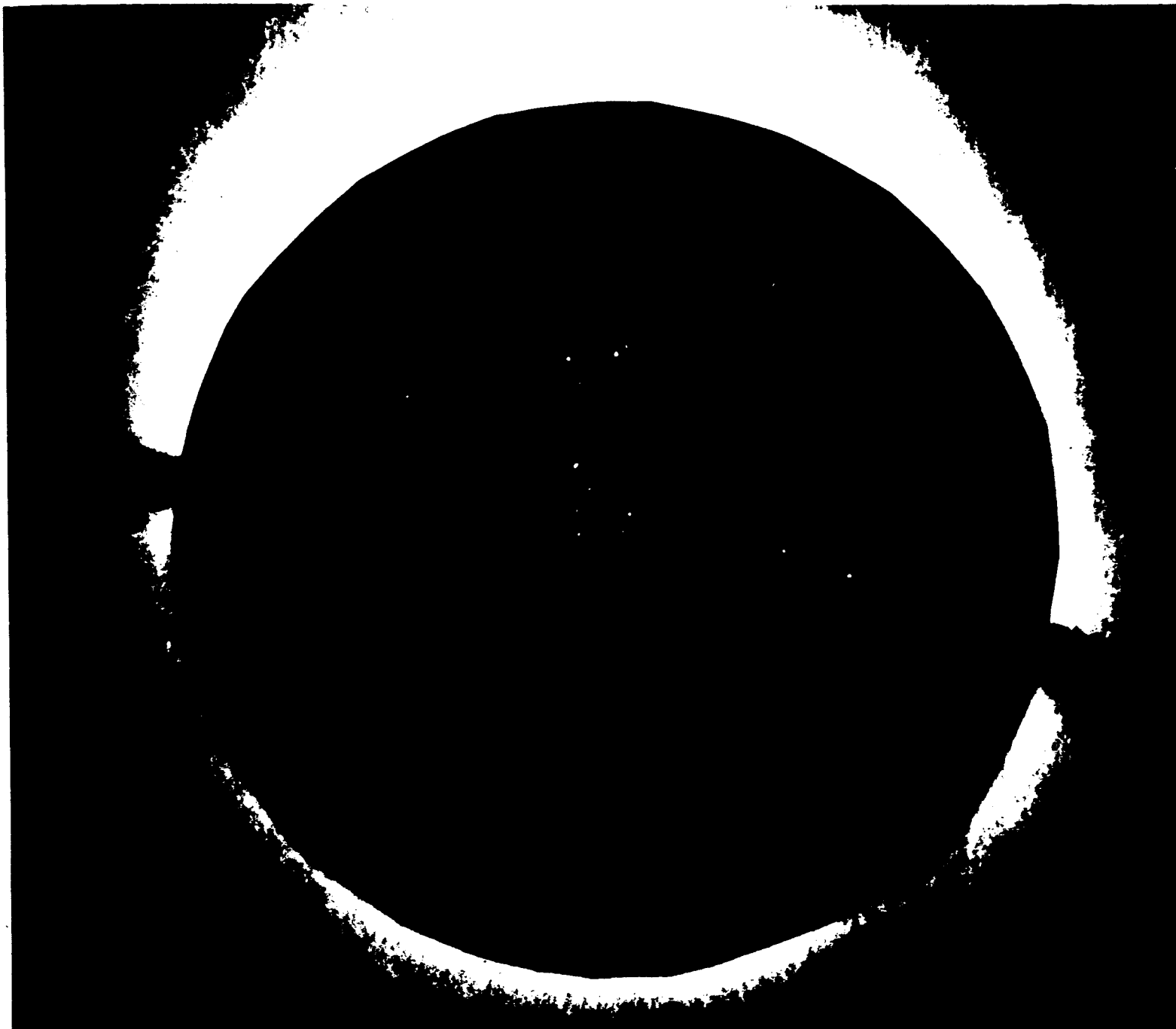
TEST NO.	PELLET	VELOCITY FT/SEC	LIGHT FT CDLS.	BLAST OVER-PRESS	GROSS EFFECT
92	.24 Inch Dia. Glass	33,400	60,000	14 PSI	Burned
93	.24 Inch Dia. Glass	33,400	9,000	14 PSI	No Burning
94	.24 Inch Dia. Glass	27,800	50,000	13 PSI	Burned
100	.24 Inch Dia. Glass	28,200	22,500	4 PSI	Burned

* Animals located below particle stream.

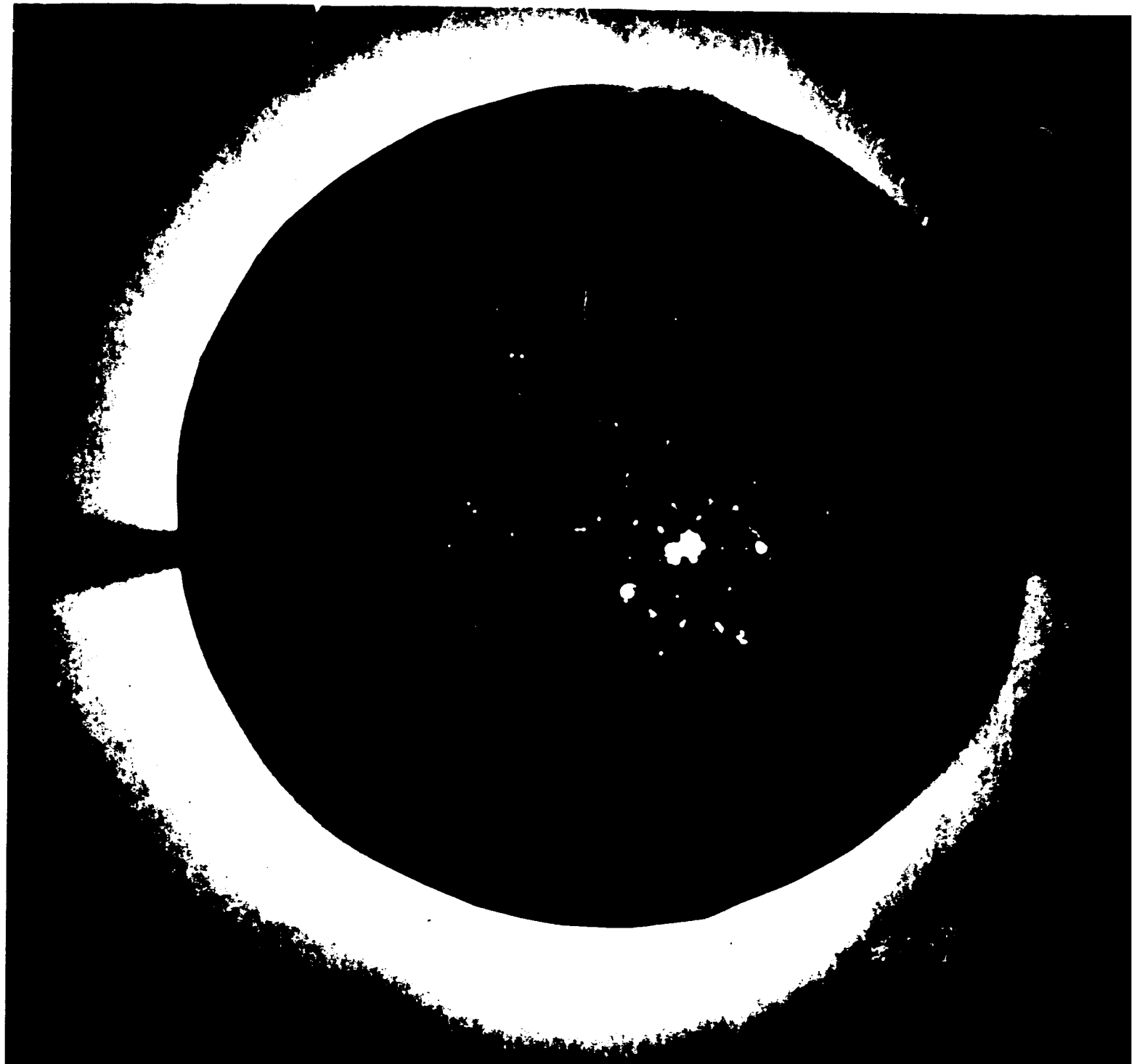
** 0.016 flat target.



Test No. 74 - No Burning
Target: .016 Aluminum (7075)
Pellet: #60 SiC
Velocity: 26,400 ft./sec.
Light: 625 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI



Test No. 77 - No Burning
Target: .016 Aluminum (7075)
Pellet: .1" Dia. x .007" Glass
Velocity: 36,000 ft./sec.
Light: 600 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI

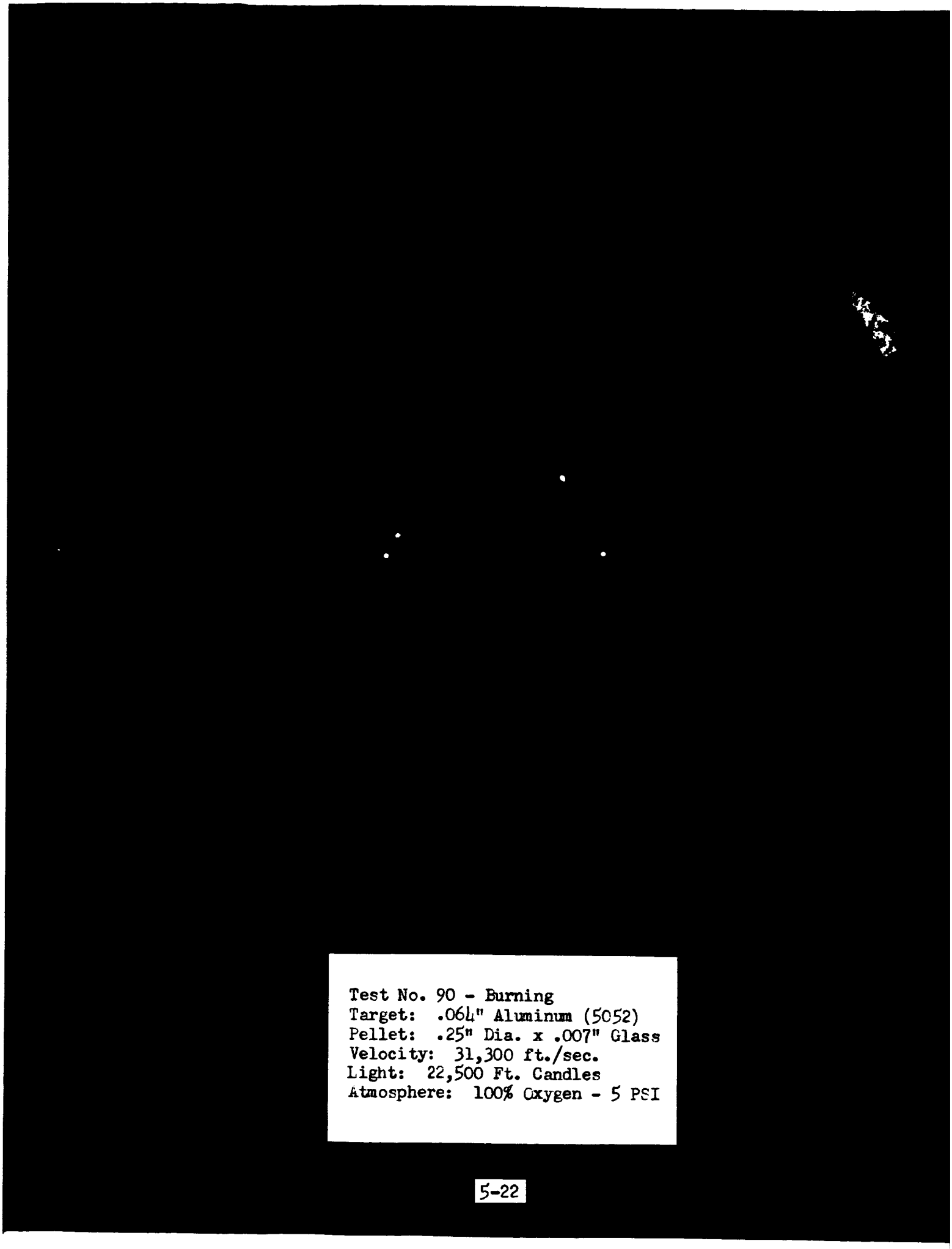


Test No. 143 - Burning
Target: .016" Aluminum (7075)
Pellet: .025" Dia. x .006" Glass
Velocity: 31,700 ft./sec.
Light: 275,000 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI

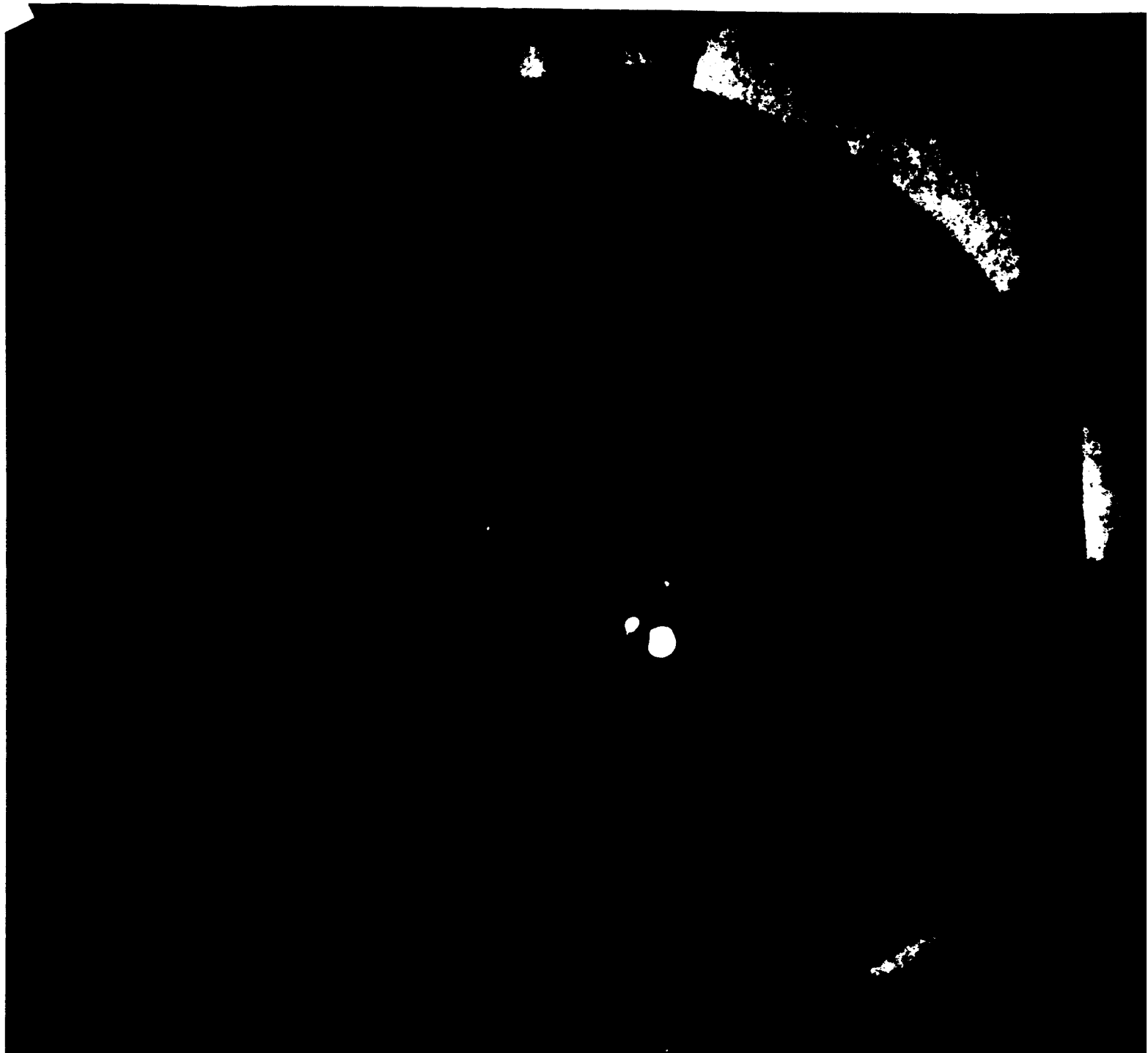
Test No. 99 - Burned
Target: .020" Aluminum (5052)
Pellet: .1" Dia. x .006" Glass
Velocity: 31,200 ft./sec.
Light: 24,800 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI

Test No. 102 - No Burning
Target: .020" Aluminum (5052)
Pellet: .1" Dia. x .006" Glass
Velocity: 37,100 ft./sec.
Light: 2,000 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI

Test No. 139 - Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 34,500 ft./sec.
Light: 60,000 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI



Test No. 90 - Burning
Target: .064" Aluminum (5052)
Pellet: .25" Dia. x .007" Glass
Velocity: 31,300 ft./sec.
Light: 22,500 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI



Test No. 92 - Burning
Target: .064" Aluminum (5052)
Pellet: .25" Dia. x .007" Glass
Velocity: 33,100 ft./sec.
Light: 60,000 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI

100% OXYGEN
3.5 PSI

5.3. 100 Percent Oxygen - 3.5 P.S.I.A.

A total of six tests were conducted at this condition. Three tests were conducted in the 4 cu. ft. chamber and three tests were conducted in the 2 cu. ft. chamber. The pellet size versus target thickness survey was again conducted in the larger test chamber. The 0.016 inch thick aluminum target and silicon carbide pellet combination was omitted.

5.3.1. 0.020 Inch Thick Hemispherical Aluminum Target

A single test was made in the 4 cu. ft. test chamber with this target and the 0.24 inch diameter glass pellet (Test No. 107). Specimen burning occurred. Two large target penetrations occurred and the specimen burned uniformly but not as completely as when higher pressures of oxygen were used. Only about one half of the hair length of the animal was consumed. The test specimen was still alive one hour after the test so was finally sacrificed. Post mortum examination did not reveal any marked difference in pathology of these specimens from that produced by burning at higher pressures of oxygen.

5.3.2. 0.064 Inch Thick Hemispherical Aluminum Target

Test numbers 96 and 101 were made using this target and 0.24 inch diameter glass pellet at this low pressure of pure oxygen. The 4 cu. ft. test chamber was used. Specimen burning occurred when the typical hypervelocity penetrations were produced in conjunction with a high recorded light intensity. Pathological findings were again not unlike those found with 5 psia-100 percent oxygen. Burning was again oxygen limited and characteristic of that obtained at this atmosphere condition. Test No. 96 produced no burning; however, the light level recorded (3000 foot candles) and the penetration lip characteristics on the back of the target are typical of those which did not produce high energy release levels, (Figure 4). A lung condition which may have been indicative of blast injury found on microscopic examination.

Three tests (Nos. 120, 121, 129) were made with the same large pellet and medium target in the 2 cu. ft. test chamber. All tests produced burning of the specimen. The penetrations were large and high velocities and light intensities were recorded. Pathological findings for these animals include third degree burns of the skin and patchy burning of the hair leaving from 3 to 5 mm of normal hair at the base. Lungs suffered the usual congestion and edema due primarily to burning. The corveal covering of the eye was made opaque in all cases. The degree of injury, particularly in the lung, was not as severe as previously observed however.

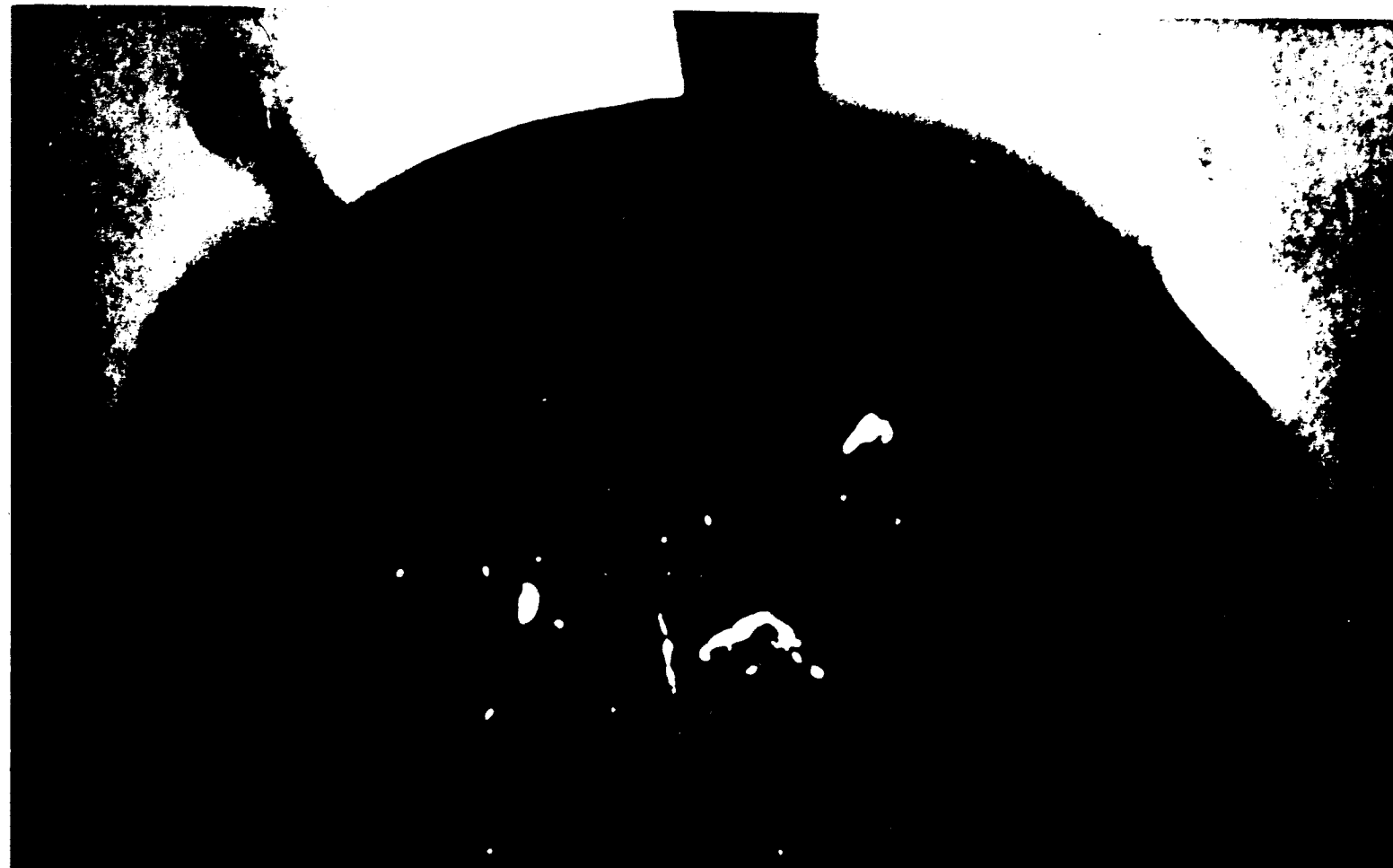
TABLE III

Test Data At 100 Percent Oxygen-3.5 PSIA Chamber Atmosphere

TEST NO.	VELOCITY FT/SEC.	LIGHT FT. CDLS.	GROSS EFFECT	BLAST OVER-PRESS	CHAMBER SIZE (CU. FT.)
.020 Inch Thick Target					
107	No Data	No Data	Burned	13 PSI	4
120	26,300	200,000	Burned	28 PSI	2
121	27,000	65,000	Burned	28 PSI	2
129	32,200	125,000	Burned	31 PSI	2
.064 Inch Thick Target					
96	29,400	3,000	No Burning	No Data	2
101	34,500	22,500	Burned	14 PSI	2

Note: All shots used .24 Inch Dia. Glass Pellets

Test No. 107 - Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: Did Not Record
Light: High (Over Exposed Polaroid)
Atmosphere: 100% Oxygen - 3.5 PSI



Test No. 120 - Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 26,300 ft./sec.
Light: 200,000 Ft. Candles
Atmosphere: 100% Oxygen - 3.5 PSI

Test No. 101 - Burning
Target: .064" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 34,500 ft./sec.
Light: 22,500 Ft. Candles
Atmosphere: 100% Oxygen - 3.5 PSI

50% OXYGEN
50% NITROGEN
7 PSI

5.4. 50 Percent Oxygen and 50 Percent Nitrogen - 7 PSI

Eleven tests were performed at this atmospheric condition. Six tests were conducted using the 4 cu. ft. test chamber and five tests were conducted using the 2 cu. ft. test chamber. No burning occurred in this series although certain types of injuries did result as noted below. All tests in this series were made with .020 inch thick hemispherical aluminum targets and .24 inch diameter glass pellets. This combination resulted in from two to ten rather large penetrations equivalent to those which produced burning in tests at 100 percent oxygen concentrations. Pathological findings included focal area of singeing but no intense burns. Areas up to two square inches were denuded of hair. Lungs and other areas are grossly normal. No difference was seen in the pathology produced in the two different sized chambers. Flash blindness and disorientation was noted when the animals were removed from the test chamber.

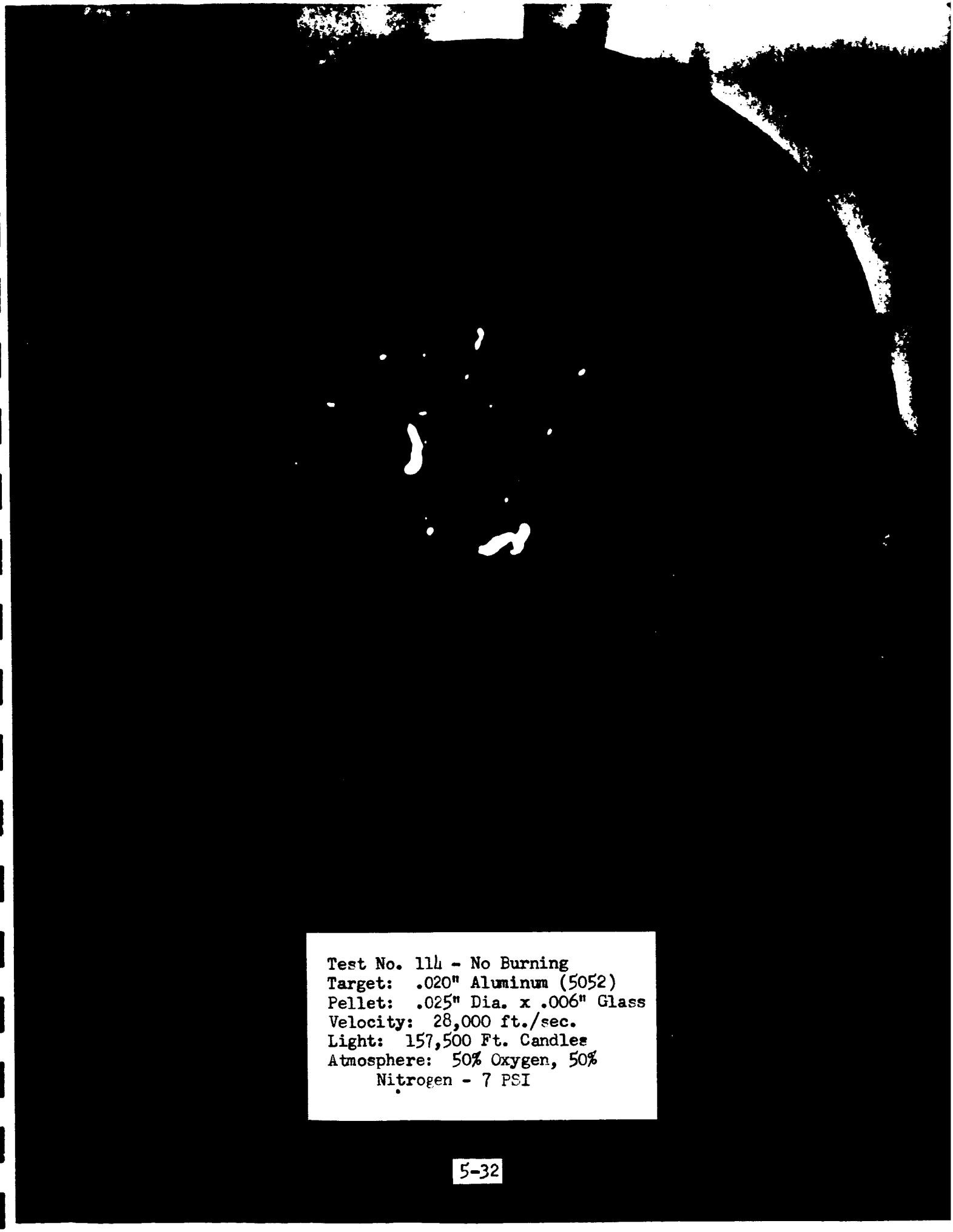
TABLE IV

Test Data At 50 Percent Oxygen - 50 Percent Nitrogen - 7 PSIA Chamber Atmosphere

TEST NO.	VELOCITY FT/SEC	LIGHT FT. CDLS.	BLAST OVER-PRESS	GROSS EFFECT
4 cu. ft. chamber - .020 Inch Thick Targets				
108	27,800	22,500	18 PSI	Singeing & Denuded Area
111	No Data	No Data	12 PSI	Singeing & Denuded Area
112	No Data	No Data	16 PSI	Singeing & Denuded Area
113	No Data	No Data	No Data	Singeing & Denuded Area
114	28,000	157,500	No Data	Singeing & Denuded Area
115	27,800	62,000	No Data	Singeing & Denuded Area
2 cu. ft. chamber - .020 Inch Thick Targets				
122	27,800	80,000	9 PSI	Singeing & Denuded Area
123	27,800	63,000	18 PSI	Singeing & Denuded Area
124	27,700	75,000	17 PSI	Singeing & Denuded Area
125	27,700	58,000	19 PSI	Singeing & Denuded Area
126	27,800	50,000	29.5 PSI	Singeing & Denuded Area

Note: Denuded areas of skin were confined and showed little injury.

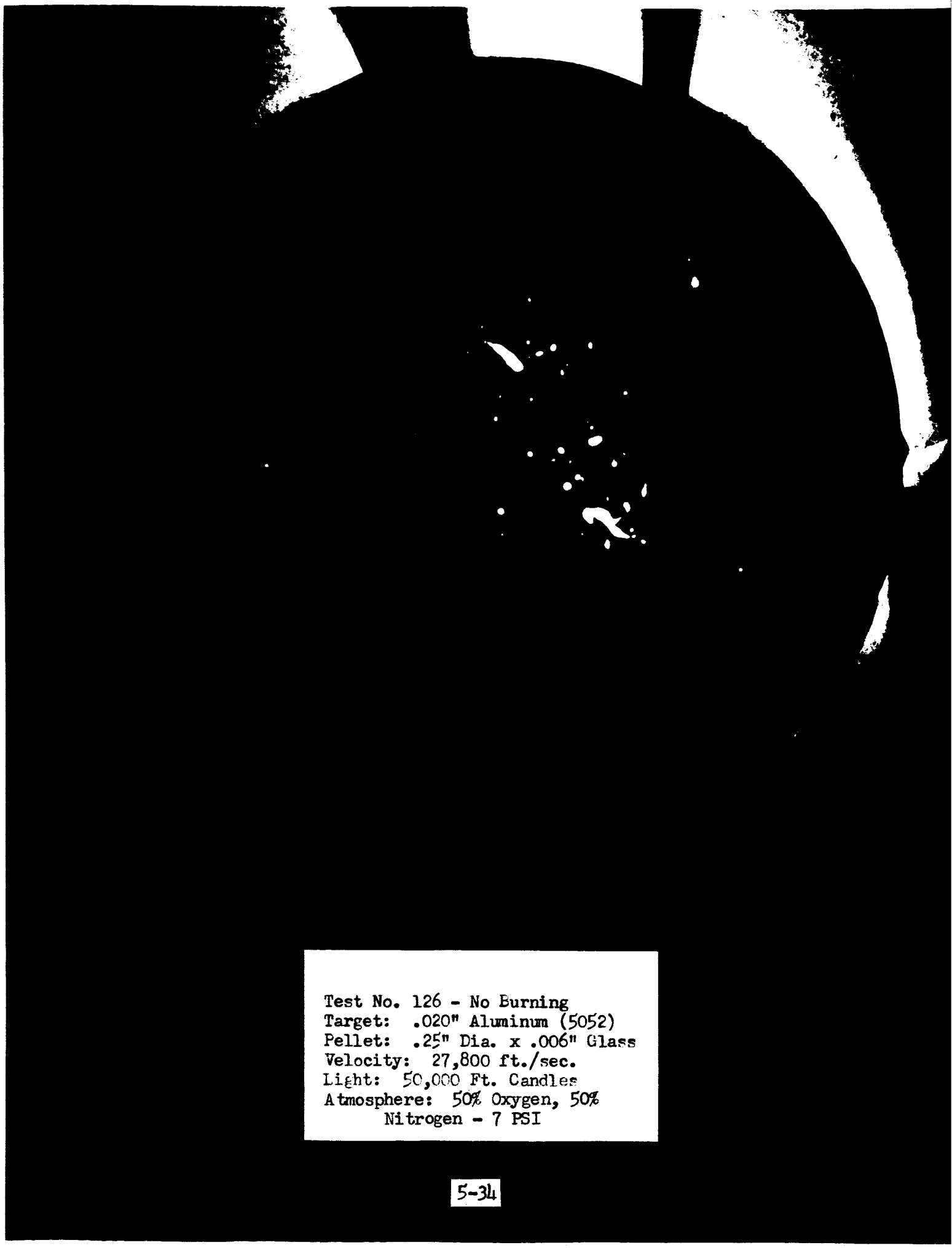
Test No. 113 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: No Reading
Light: Off Scale
Atmosphere: 50% Oxygen, 50%
Nitrogen - 7 PSI



Test No. 114 - No Burning
Target: .020" Aluminum (5052)
Pellet: .025" Dia. x .006" Glass
Velocity: 28,000 ft./sec.
Light: 157,500 Ft. Candles
Atmosphere: 50% Oxygen, 50% Nitrogen - 7 PSI

Test No. 123 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 27,800 ft./sec.
Light: 63,000 Ft. Candles
Atmosphere: 50% Oxygen, 50% Nitrogen - 7 PSI

AMBIENT ATMOSPHERE



Test No. 126 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 27,800 ft./sec.
Light: 50,000 Ft. Candles
Atmosphere: 50% Oxygen, 50% Nitrogen - 7 PSI

5.5 Ambient Atmosphere

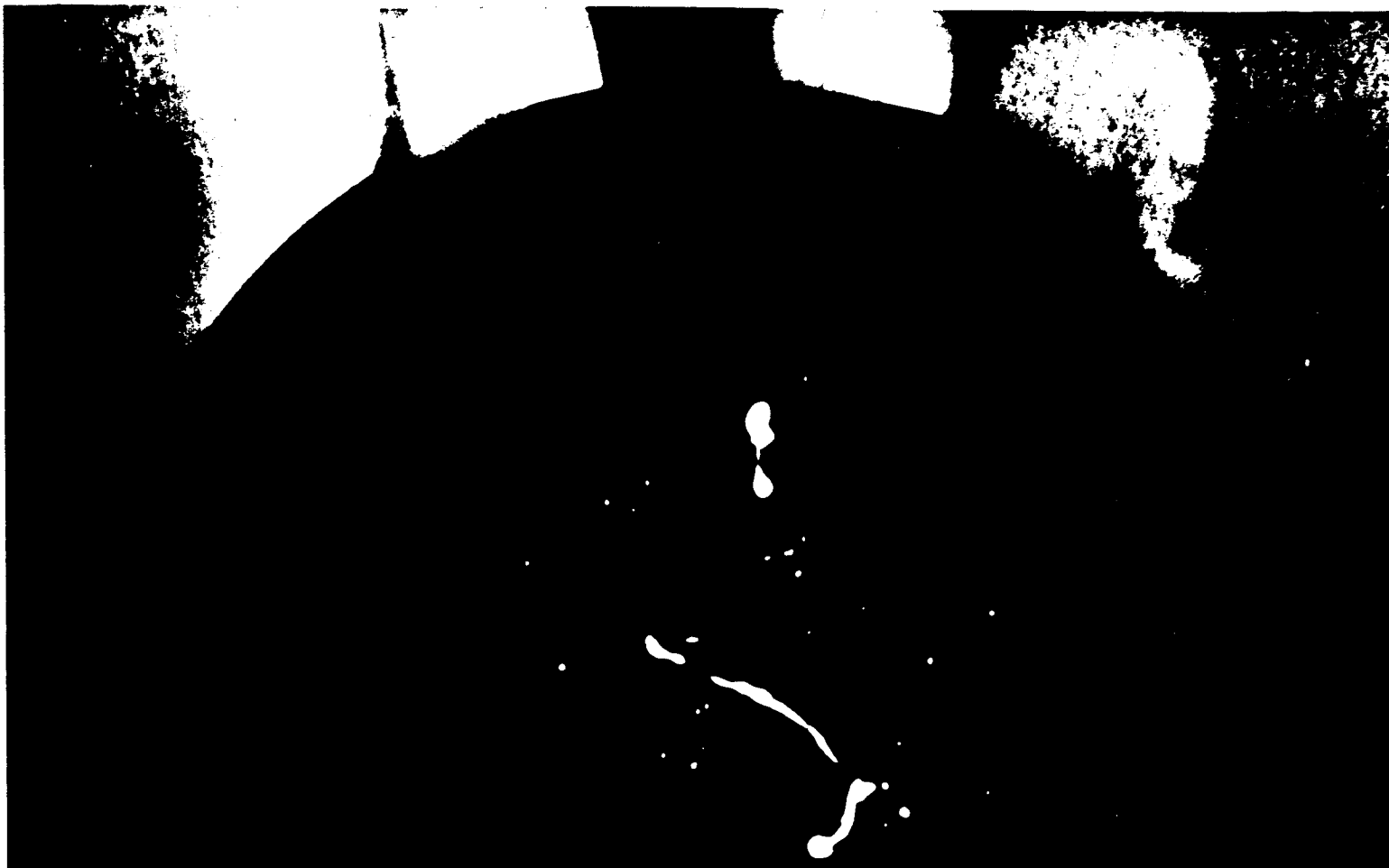
Four tests were conducted at this atmospheric condition in the 4 cubic foot test chamber and the same number in the 2 cubic foot test chamber. The 0.20 inch thick hemispherical aluminum target and the 0.25 inch diameter glass pellet were again used. The holes produced in these targets varied in size and frequency. On those targets with larger penetrations and higher light intensity, injury of the specimen was produced. These animals were obviously in much better condition than those tested at any other atmosphere employed in the program. Pathological examination showed no gross abnormalities. In areas of singeing the hair at the base was normal. Again flash blindness and slow response were observed after the test. On test No. 127 an injury to the left thigh of the specimen was produced by spalled wall material. No diffuse burning occurred. (Pathology, Test No. 127). These data are summarized as follows:

TABLE V
Test Data At Standard Atmosphere Chamber Condition

TEST NO.	VELOCITY FT/SEC	LIGHT FT. CDLS.	BLAST OVER-PRESS	GROSS EFFECT
4 cu. ft.				
116	27,800	20,000	14 PSI	No Burning
117	27,500	48,000	17 PSI	No Burning
118	30,000	50,000	24 PSI	No Burning
119	31,300	80,000	36 PSI	No Burning
2 cu. ft.				
127	27,300	65,000	38 PSI	No Burning
130	29,400	15,000	30 PSI	No Burning
131	28,500	33,000	32 PSI	No Burning
132	31,000	33,000	34 PSI	No Burning

Test No. 116 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 27,800 ft./sec.
Light: 20,000 Ft. Candles
Atmosphere: Ambient

Test No. 119 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 31,300 ft./sec.
Light: 80,000 Ft. Candles
Atmosphere: Ambient



Test No. 127 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006 Glass
Velocity: 27,300 ft./sec.
Light: 65,000 ft. Candles
Atmosphere: Ambient

DEPILATED ANIMALS

5.6. Special Conditions

Two test series were conducted to resolve the importance of two specific variables on the degree of injury produced by the oxidative explosion. One series was designed to study the results of removing the combustible material (hair) from the test specimen. The second series was designed to evaluate the effects of reducing the number and size of particle penetrations. Certain limitations exist in the design of each of these series. These are described along with the results. Both series were in the 2 cu. ft. chamber.

5.6.1. Tests Using Depilated Specimens

Five tests were made using specimens from which the hair had been removed. All of these tests were made using 0.020 inch thick hemispherical aluminum targets and 0.24 inch diameter glass pellets. Two atmospheric conditions were used in the cabin chamber.

100 Percent Oxygen - 5 P.S.I.A. - The first test conducted used a rat from which the hair was removed by clippers and a razor. The hair was completely removed except for that around the eyes, ears, mouth and scrotum. Energy release upon target penetration still caused burning of the specimen. The hair was burned down into the follicles, and the lips and ear tissue was partially consumed. The dry skin scale of the tail, was also burned. Figure A-5 shows this specimen immediately after the test. Although intense burns were produced in the areas where hair stubble remained, areas which had been clearly shaved were much less severely injured.

The remaining two animals tested at 100 percent oxygen at 5 P.S.I.A. were depilated using Nair (Trademark). This chemical agent was adopted to achieve more complete hair removal. Unfortunate side effects were produced, however, including blistering of the skin, and eye irritation. The latter

caused the animals to keep their eyes closed during the tests. Almost all of the dry layers of epidermis were removed by the Nair treatment, leaving a pink, wet appearing skin surface with some blisters forming before the test, Figure A-1. This must be considered when reviewing the test results.

The remaining tests at 100% oxygen - 5 P.S.I.A. produced no burning although some of the dry scale on the tail of the specimens was, as before, blackened or oxidized slightly. Target plate penetration on the second test of the series produced the only serious internal injury of this test series. A particle of either target material or pellet penetrated the peritoneal cavity of the test specimen. Energy release phenomenon, typical of hypervelocity impact, then occurred inside the animal. A large hole was made in the large intestine, and a series of tears or holes were produced in the small intestine. Contents of the large intestine were ejected back to the target plate and to other points in the test chamber. The result obtained was similar to that of a test conducted over two years ago in which hypervelocity aluminum particles penetrated a sponge impregnated with an agar-gelatin. Skin burns were widespread but were probably due to the depilatory. All of these animals were partially anesthesized prior to hair removal and during the test, preventing valid assessment of gross animal behavior.

Third degree burns resulted on the animal from which the hair had not been completely removed; however, burning to the deeper dermis did not occur as in previous burnings. On the other two animals no thermal burn was detected. The lung damage was consistent with other specimen tested at this atmosphere. Microscopic examination of a section of the lung indicated a condition which could be produced by blast injury. Fastax camera records indicate that flames lingered over the surface of one animal after the initial aluminum oxidative explosion subsided. The combustible material is not known.

It could have been oils produced by the skin or a solvent used in the Nair depilatory. The excess depilatory was removed with soap and water before each test, however, intense loss of epidermis was observed. There was no evidence of thermal burn. No. 145 suffered a shrapnel wound. The lungs of all the naked specimens except the one that burned, showed areas of lung collapse (at electasis) and other areas of gas infusion and distension (emphysema) associated with blast and heat injury. Congestion was also noted.

100 per cent oxygen - 14.7 P.S.I.A. - Two tests were conducted using the depilitated specimens to determine if the skin, although modified by the Nair treatment, could be induced to burn at this atmosphere. The specimens became marked ly dehydrated and covered with resolidified particles of molten aluminum. The specimens did not burn. Lung damage, as described above, was observed in autopsy, along with some eye damage. The small amount of eye damage may have been a result of the eyes being closed during the test. The eyes of the animals were closed as a result of general irritation caused by the Nair. These data are summarized as follows:

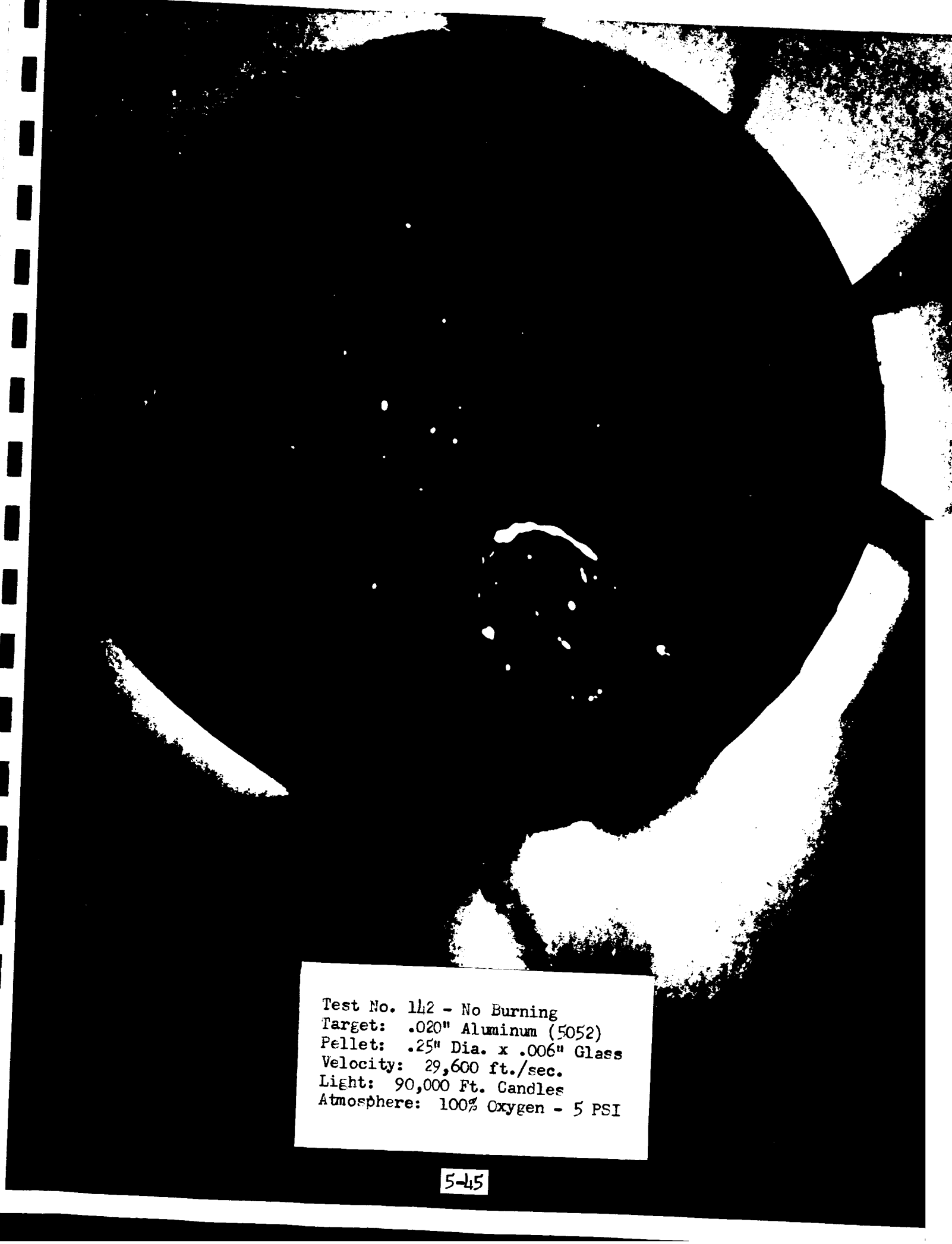
TABLE VI

Test Result Using Depilated Specimens

TEST NO.	VELOCITY FT/SEC	LIGHT FT. CDLS.	BLAST OVER-PRESS	GROSS EFFECT
5 P.S.I.A.				
140	29,400	150,000	12 PSI	Burned where hair not completely removed
141	No data	65,000	12 PSI	No Burning
142	29,600	90,000	20 PSI	No Burning
14.7 P.S.I.A.				
144	30,800	75,000	No data	No Burning
145	30,800	200,000	36 PSI	No Burning

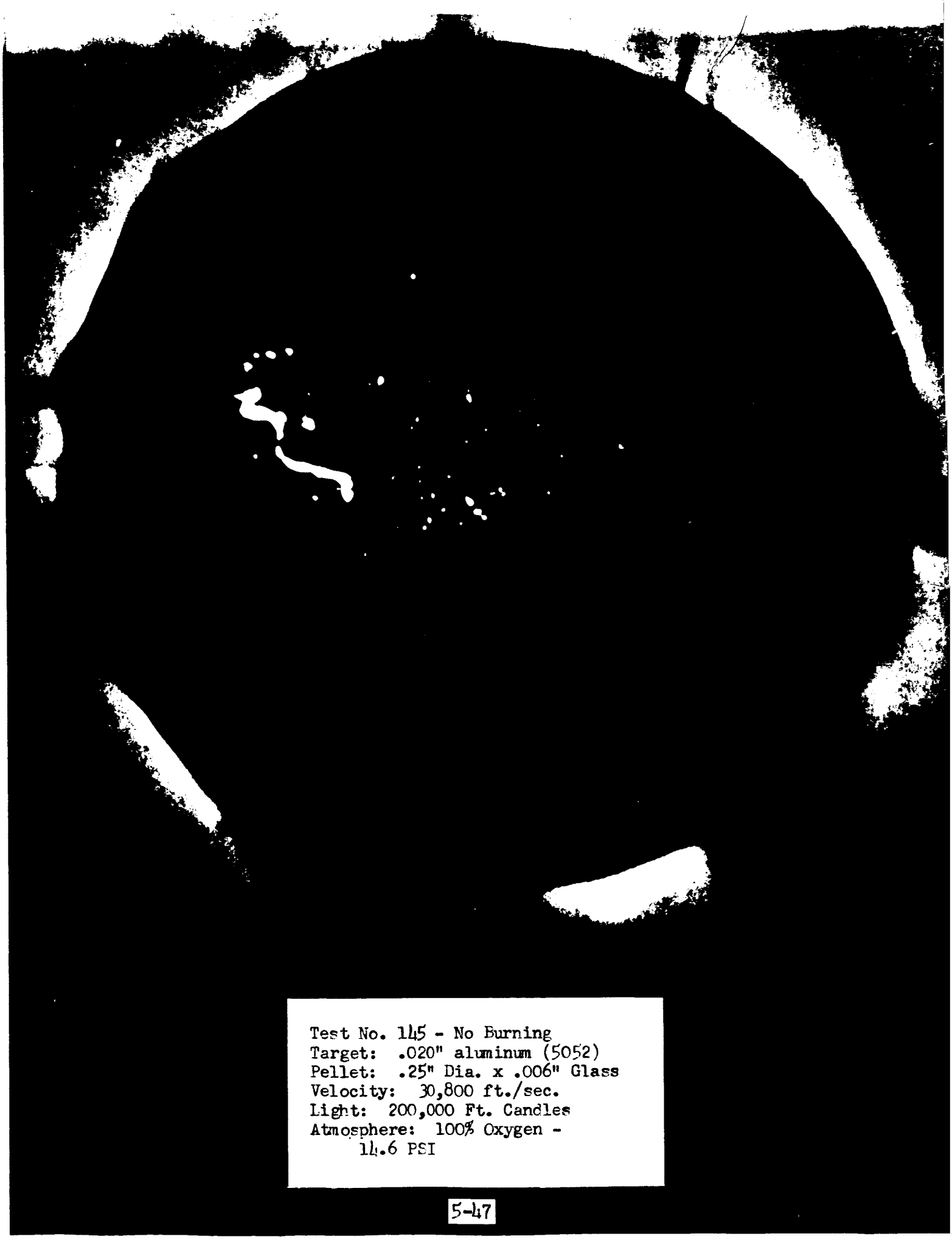
Test No. 140 - Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 29,400 ft./sec.
Light: 150,000 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI

Test No. 141 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: Not Recorded
Light: 65,000 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI



Test No. 142 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 29,600 ft./sec.
Light: 90,000 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI

Test No. 144 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 30,800 ft./sec.
Light: 75,000 Ft. Candles
Atmosphere: 100% Oxygen -
14.6 PSI



Test No. 145 - No Burning
Target: .020" aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 30,800 ft./sec.
Light: 200,000 Ft. Candles
Atmosphere: 100% Oxygen -
14.6 PSI

SCREENED TARGETS

5.6.2. Tests Using the Particle Screen

In this series of tests a thick aluminum plate was placed in front of the target plate. A series of holes was drilled in the plate which would allow only those particles passing through these holes to impact upon the target. In eleven of 21 tests no penetrations occurred, since all particles missed the holes in the screen. One disadvantage of this test technique was that the velocity of the penetrating particles could not be accurately determined.

An additional photodiode was installed in front of the target in an attempt to gain velocity information based on recording impact on the screen. No distinction could be made, however, between the highest and lowest velocity particles in the particle stream. The light produced behind the target by some small penetrations was not sufficient, in most cases, to trigger the memeoscope even when all light filters were removed from the photodiodes. When large penetrations were made under this condition the velocity data was lost due to transducer saturation. Examination of the impact patterns on the particle screen also revealed that some of the small particles which penetrated the target had been broken off of larger particles which hit the edge of a hole in the screen. It is probable that the fragment subsequently penetrating the target plate would have been slowed down by the initial impact, and the necessity for overcoming the adhesvie force of the rest of the mass. Most of the penetrations appeared to be produced by hypervelocity particles, however. Of the ten tests in which penetrations occurred, only one was made at the atmospheric condition of 100 percent oxygen - 14.7 P.S.I.A.

At this atmosphere the single 0.02 inch penetration did not produce sufficient light inside the chamber to record. A particle velocity of 31,800 ft/sec was established for the first particles to impact against the heavy aluminum screen. This velocity is not one which can be specifically assigned to the penetrating particle. It may however, establish the velocity range in which the particle belongs. Pathological examination did not reveal significant injury to the test specimen.

The other nine tests in which penetration occurred were conducted at 5 P.S.I.A. 100 percent oxygen. The penetrating particles produced holes of various sizes. Again, light intensity produced was low and only four velocities were recorded. Test No. 154 had the highest light production, 25,000 foot candles, and produced specimen burning of the normal 5 P.S.I.A. 100 percent oxygen type. The hole produced was approximately 0.24 inch in diameter. In test No. 161, five particles made four widely spaced holes with diameters ranging from 0.02 to 0.08 inches. The light intensity recorded was 2750 foot candles. Injury found in pathological examination was limited to small foci of hemorrhage on the side of the animal facing the target. Although mild pulmonary edema and congestion were found, it cannot be conclusively identified with the test stressors. Test No. 162, with only a single penetration of 0.02 inch diameter, did not produce sufficient light to record. Pathological findings consisted of only mild hair singe and some lung congestion and edema. The latter again could have resulted from natural disease. Flash blindness was detected in the specimen from test No. 161, but was not found to occur in the other specimens when single small penetrations occurred.

The above tests are indicative of the range of results obtained using the screen technique for penetrating particle reduction. These data are summarized in Table VII.

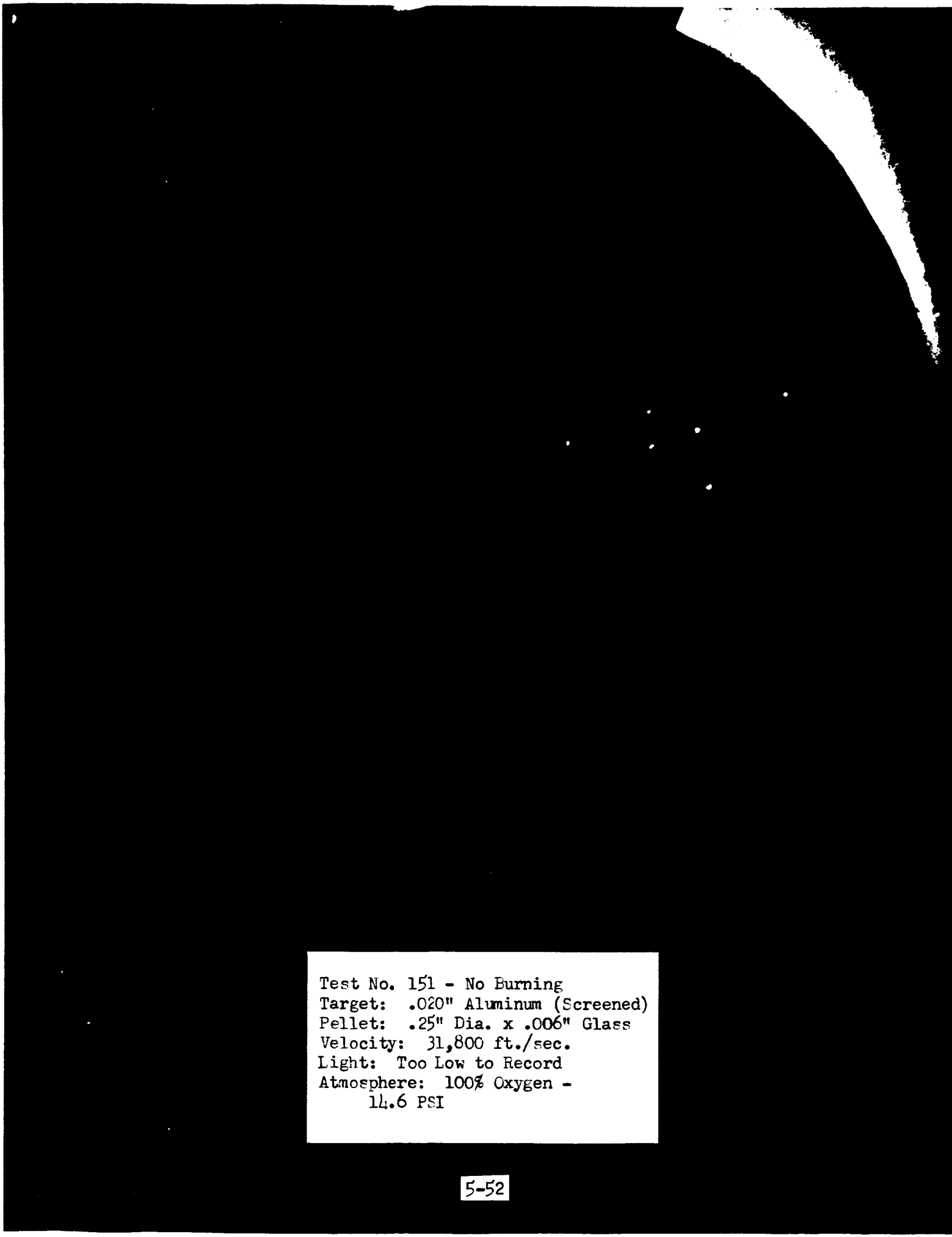
TABLE VII

Test Results with Restricted Particle Penetration

TEST NO.	ATMOS. O_2 - PSIA	VELOCITY FT/SEC	LIGHT FT. CDLS.	GROSS EFFECT
.020 Targets				
146	100% - 5	33,300	No Data	No Penetrations
147	100% - 5	28,600	No Data	2 Small Penetrations
148	100% - 5	31,300	No Data	No Penetrations
149	100% - 14.7	33,300	No Data	No Penetrations
150	100% - 14.7	35,200	No Data	No Penetrations
151	100% - 14.7	31,800	No Data	1 Small Penetration
160	100% - 5	32,300	No Data	No Large Penetrations
161	100% - 5	31,000	2,750	4 Small Penetrations
162	100% - 5	31,000	No Data	1 Small Penetration
163	100% - 5	30,300	22,500	No Burning
164	100% - 5	33,000	No Data	2 Small Penetrations
165	100% - 5	32,000	No Data	1 Small Penetration
167*	100% - 5	30,300	5,500	1 Small Penetration
.064 Targets				
152	100% - 5	31,000	No Data	No Penetrations
153	100% - 5	30,000	No Data	No Penetrations
154	100% - 5	30,300	25,000	Burned
155	100% - 5	31,300	No Data	No Penetrations
156	100% - 5	34,500	No Data	No Penetrations
157	100% - 5	No Data	No Data	No Penetrations
158	100% - 5	33,300	No Data	No Penetrations
159	100% - 5	33,300	No Data	1 Spall

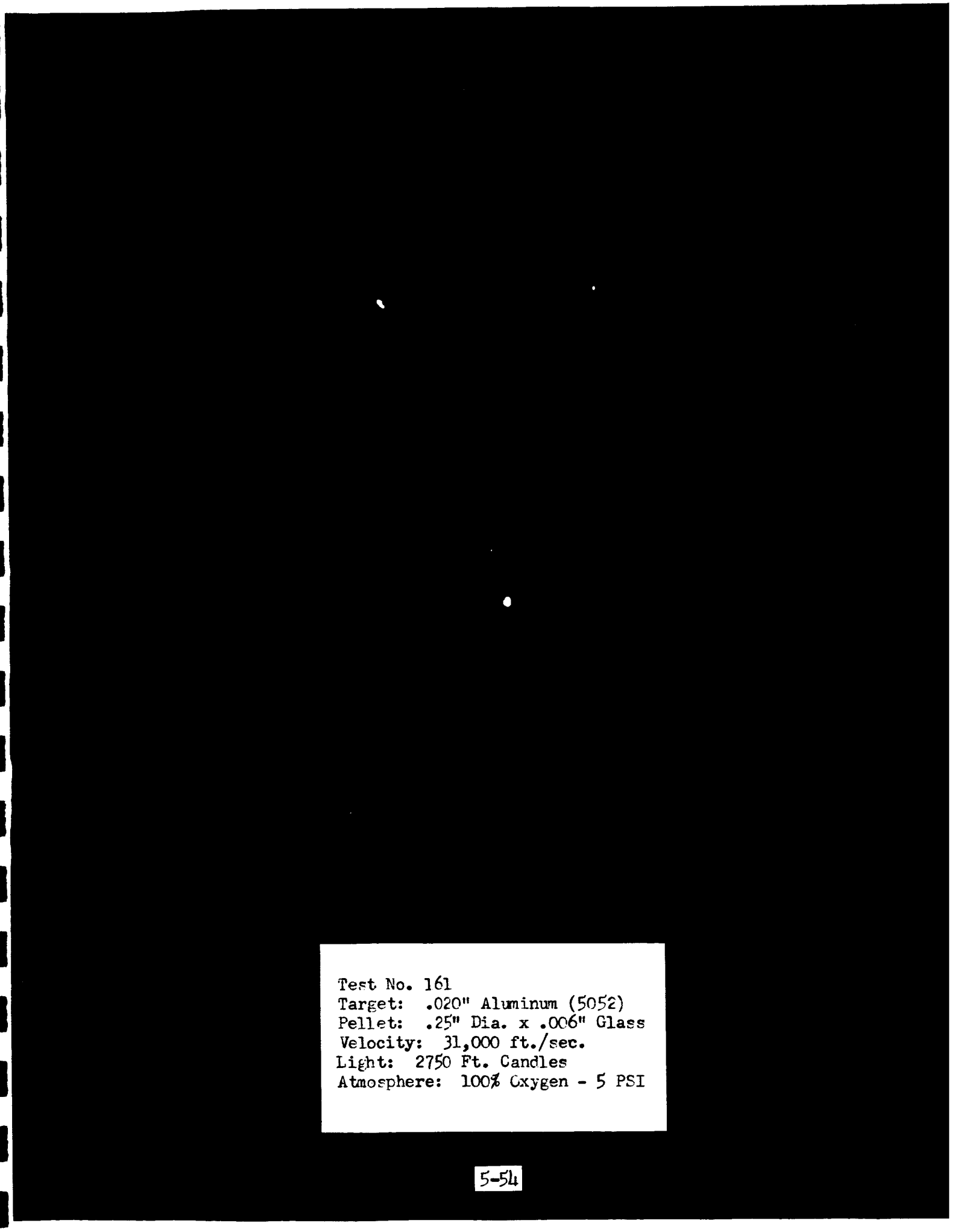
Note: Blast over-pressure too low to record.

* Titanium #4901 Flat Target Plate.



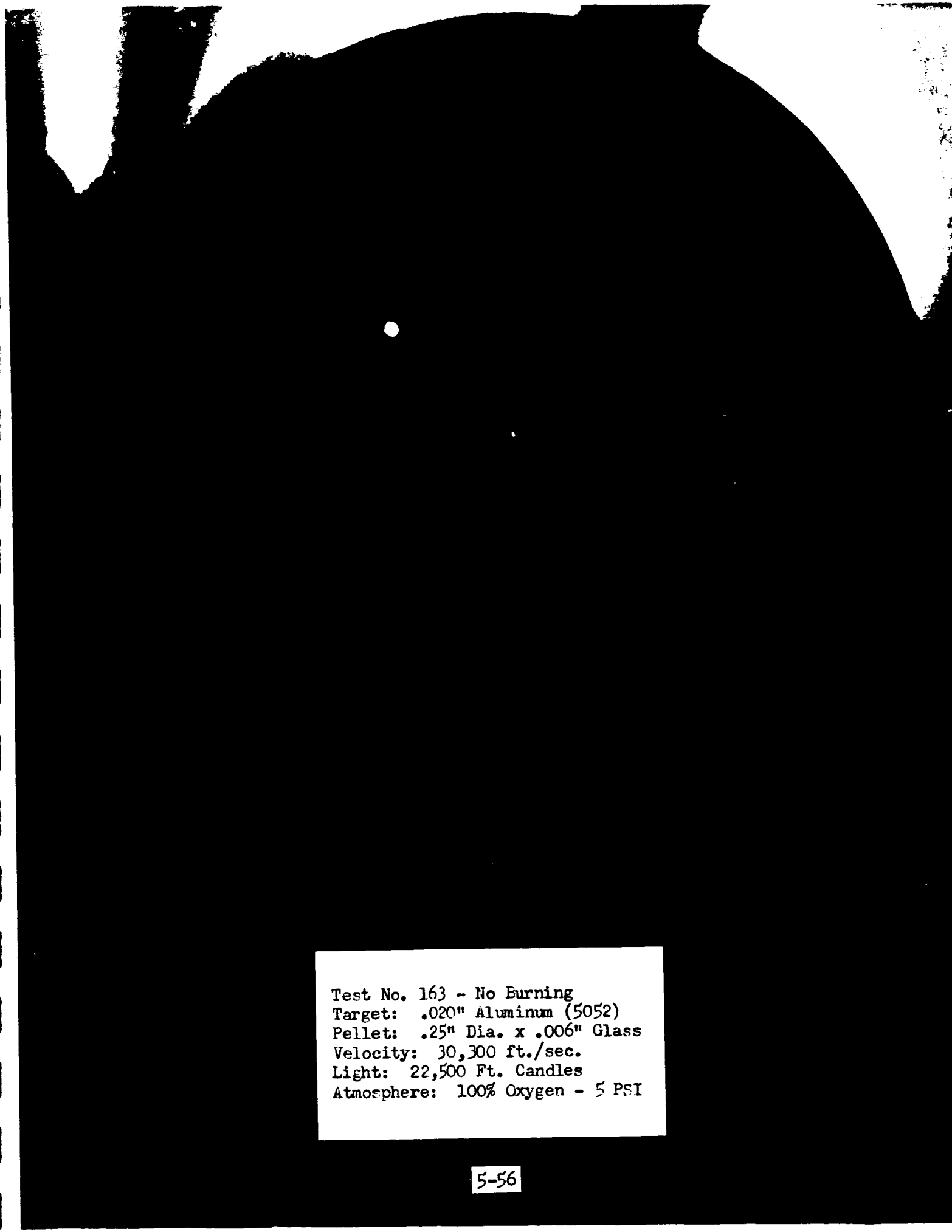
Test No. 151 - No Burning
Target: .020" Aluminum (Screened)
Pellet: .25" Dia. x .006" Glass
Velocity: 31,800 ft./sec.
Light: Too Low to Record
Atmosphere: 100% Oxygen -
14.6 PSI

Test No. 160 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 32,300 ft./sec.
Light: Too Low to Record
Atmosphere: 100% Oxygen - 5 PSI

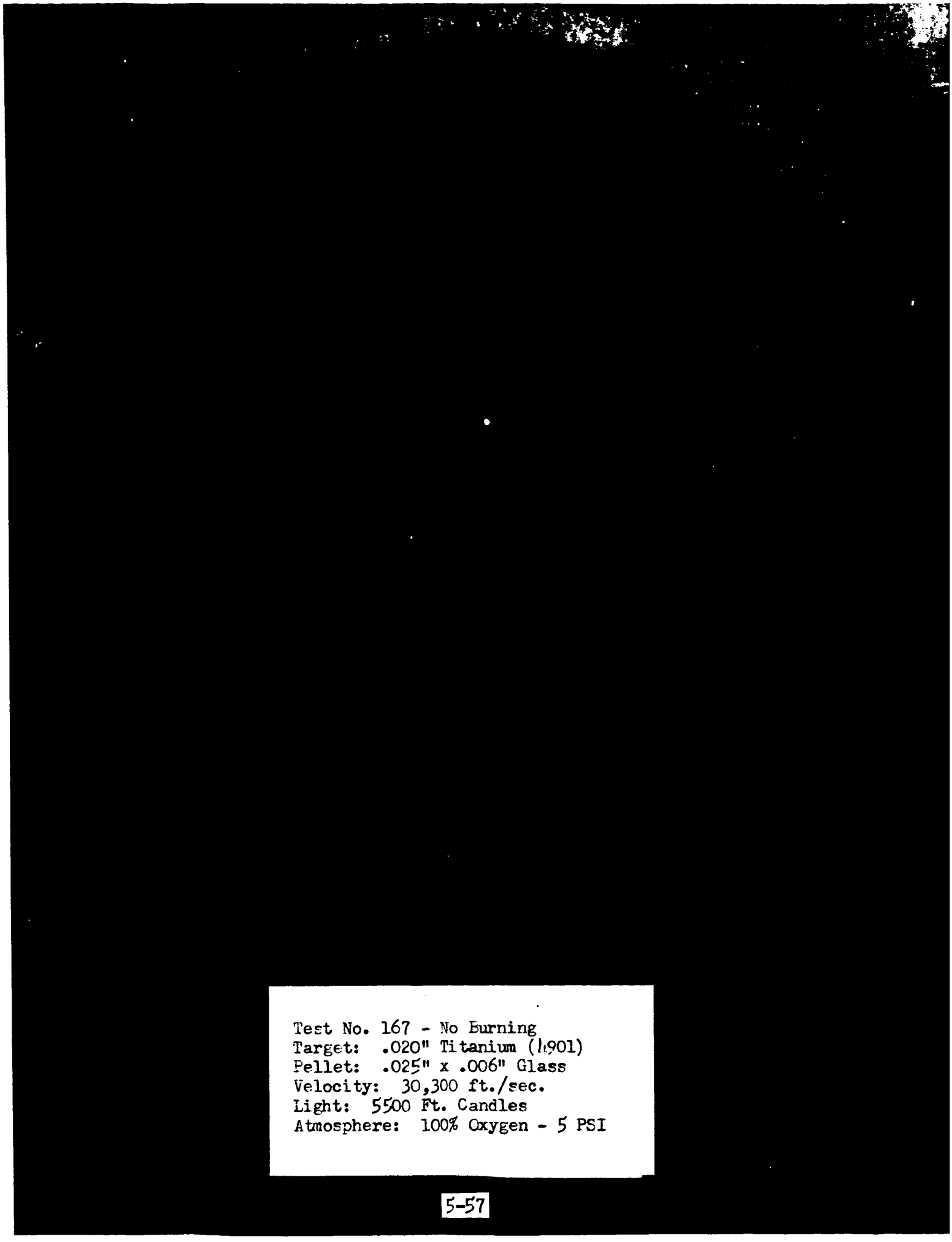


Test No. 161
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 31,000 ft./sec.
Light: 2750 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI

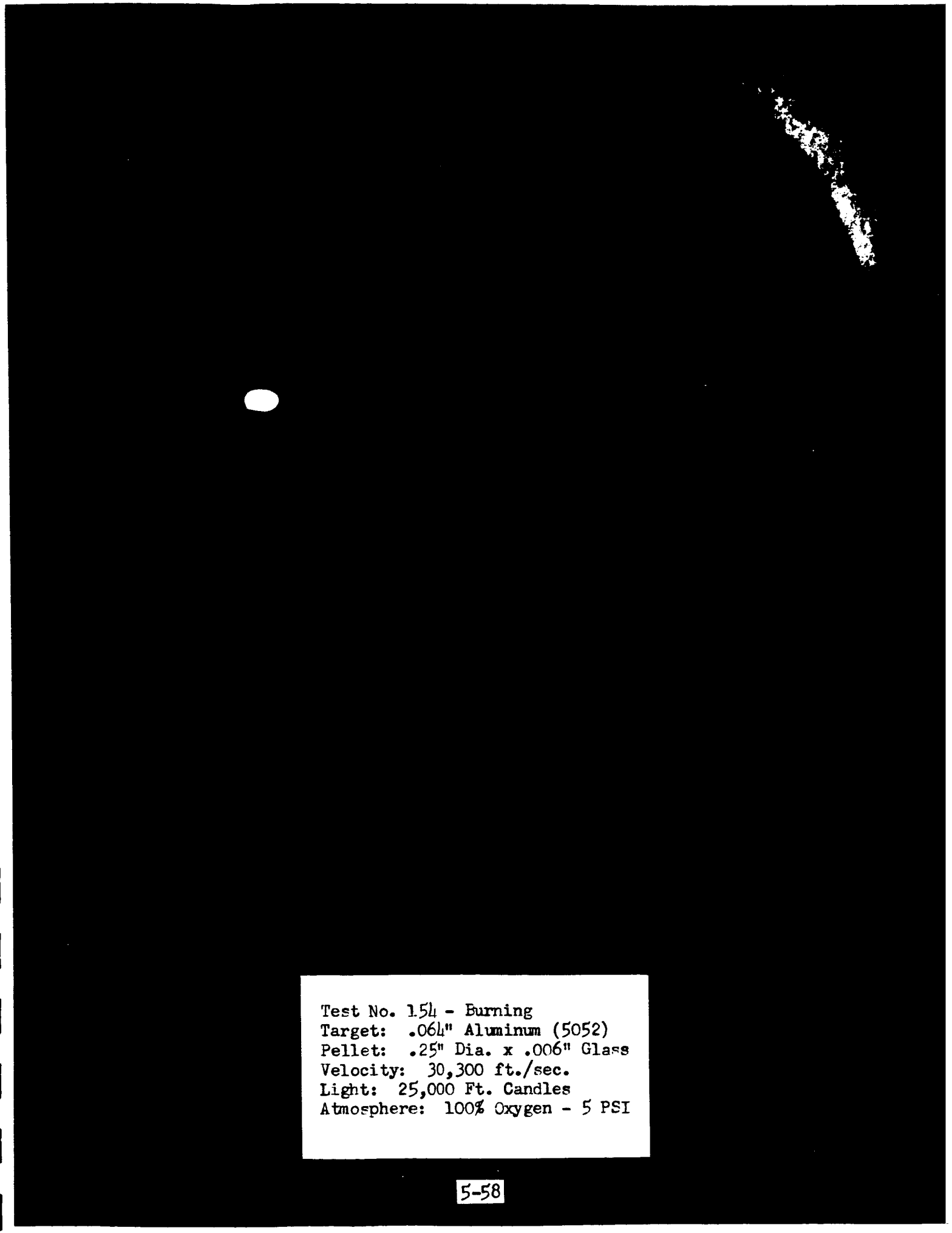
Test No. 162
Target: .020" Aluminum
Pellet: .25" Dia. x .006" Glass
Velocity: 31,000 ft./sec.
Light: Too Low to Record
Atmosphere: 100% Oxygen - 5 PSI



Test No. 163 - No Burning
Target: .020" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 30,300 ft./sec.
Light: 22,500 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI



Test No. 167 - No Burning
Target: .020" Titanium (1901)
Pellet: .025" x .006" Glass
Velocity: 30,300 ft./sec.
Light: 5500 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI



Test No. 154 - Burning
Target: .064" Aluminum (5052)
Pellet: .25" Dia. x .006" Glass
Velocity: 30,300 ft./sec.
Light: 25,000 Ft. Candles
Atmosphere: 100% Oxygen - 5 PSI

GENERAL DISCUSSION

5.7 General Discussion

The primary objective of this study was to identify a physiologically acceptable breathing atmosphere which would afford maximum protection for space crews in the event of meteoroid penetration of the manned module of a spacecraft or a crewman's full pressure suit. Based simply on the results of tests conducted at the five atmospheric conditions, the least injury occurred when the test chamber contained the lowest concentration of oxygen.

Atmospheric air had the lowest concentration of oxygen of the atmospheres considered in this study. Since the weight penalty associated with providing standard atmospheric composition and pressure in manned spacecraft is undesirable, the next lowest concentration used in these tests appears to be a more logical choice. Fifty percent oxygen and fifty percent nitrogen at 7 psia is already being considered for crew station use in U.S. manned spacecraft. This study supports its selection based on the protection it provides in the event of meteoroid penetration of the crew compartment.

There is perhaps a great deal more which can be learned from this data. Although none of the test specimens were burned at the 50 percent concentration of oxygen, injury did occur. The severity of the injury, had there been a man in the test chamber, cannot be accurately estimated. The specimen's hair was completely removed over an area of two square inches in one test. The fact that a severe local skin burn did not occur under this area is surprising. One possible explanation is that the hair acted as an "energy absorber" as defined in a study recently completed for the National Aeronautics and Space Agency, "The Principles of Meteoroid Protection," (Reference 3). In this report an effective meteoroid shield is defined as one consisting of a dense barrier, such as metal plate to disrupt the

particle on impact. This barrier would be located immediately in front of an "energy absorber". The latter is generally defined as a layer of low density material such as a polystyrene foam. The "energy absorber" in a spacecraft would be nothing more than a layer in the outer structure provided for safe attenuation of the energy released. Without this absorber the disrupted particle and displaced target material produced in penetration would be dissipated against whatever was next in its path. The form of the energy release would depend to a degree on the composition of the gaseous atmosphere behind the barrier. In these studies oxygen was present and the displaced plate or barrier was almost completely oxidized. When it was not, the particle stream apparently remained more intact and produced structural damage such as that shown in Figure 5.

Obviously when a living specimen is behind this barrier, as was the case in these tests, oxygen must be present in the atmosphere. Therefore, when the penetration of the target or barrier occurred, the debris produced was oxidized at an explosive rate. Intense heat, light, and moderate blast pressure were recorded. As was seen in the description of the results, the amount of energy released in this form depended, in part, upon the concentration of oxygen, the velocity of the penetrating particle, the size and number of particles penetrating, and the thickness of the targets. Other parameters are involved which are not included here. The following discussion deals with the various forms of energy released, the kinds of injuries they produced, and the manned in which the penetration characteristics affected the degree of injury.

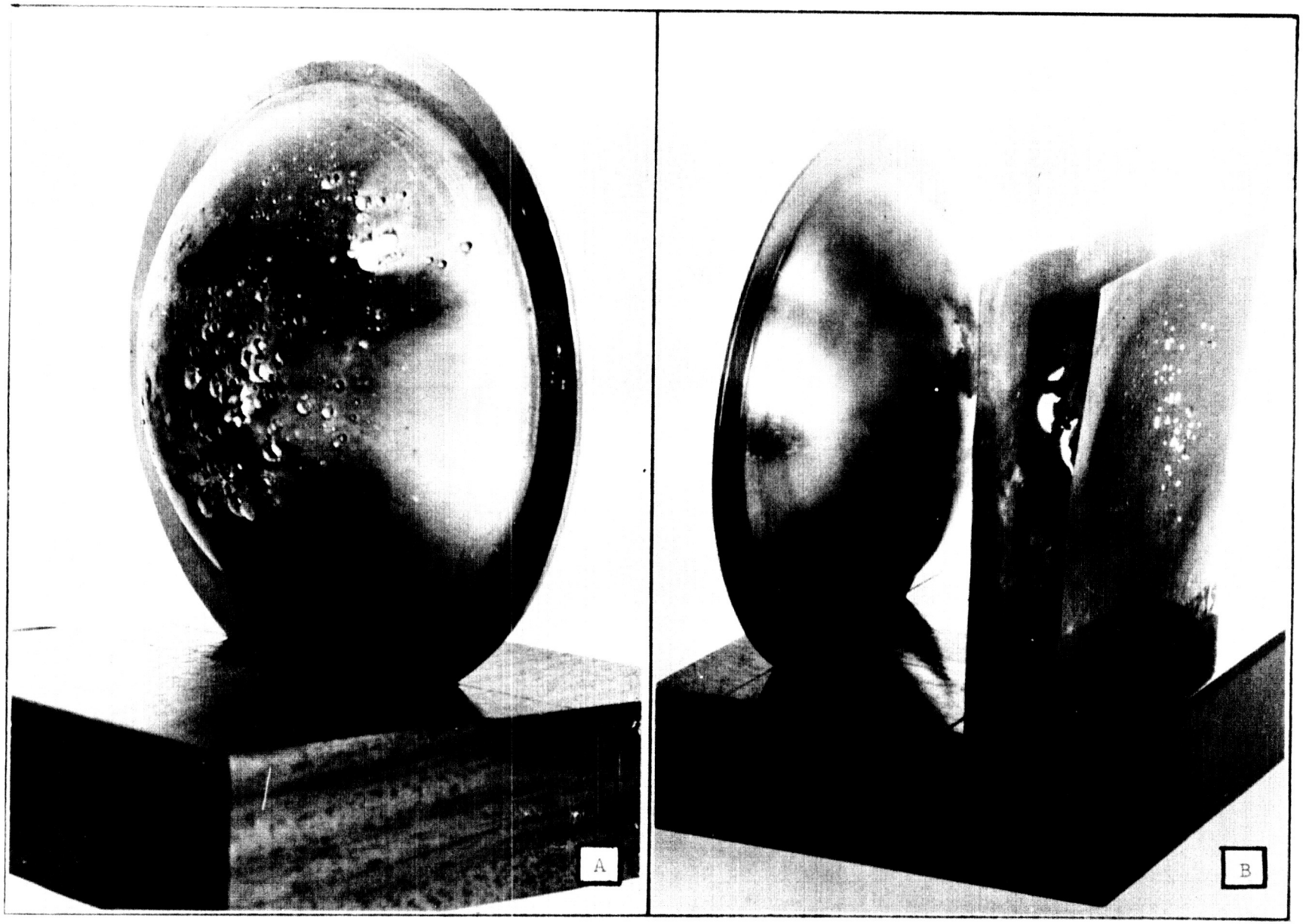
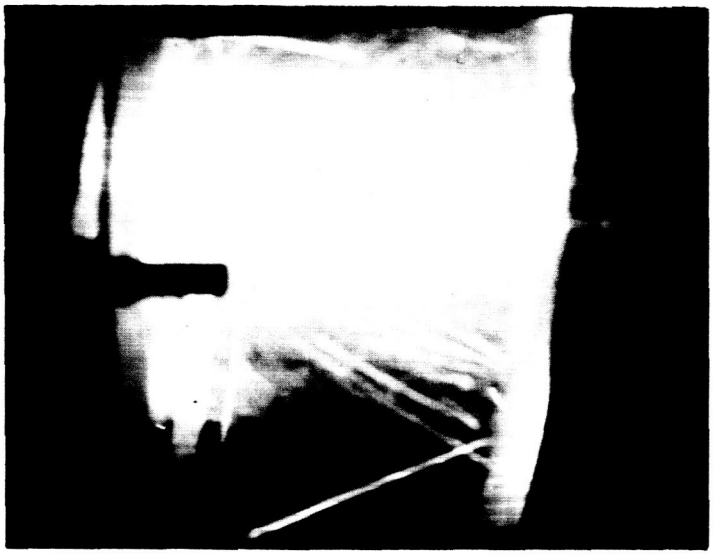


FIGURE 5. PROTECTED AND UNPROTECTED TARGETS AFTER EXPOSURE TO PARTICLES FIRED AT HYPERVELOCITIES

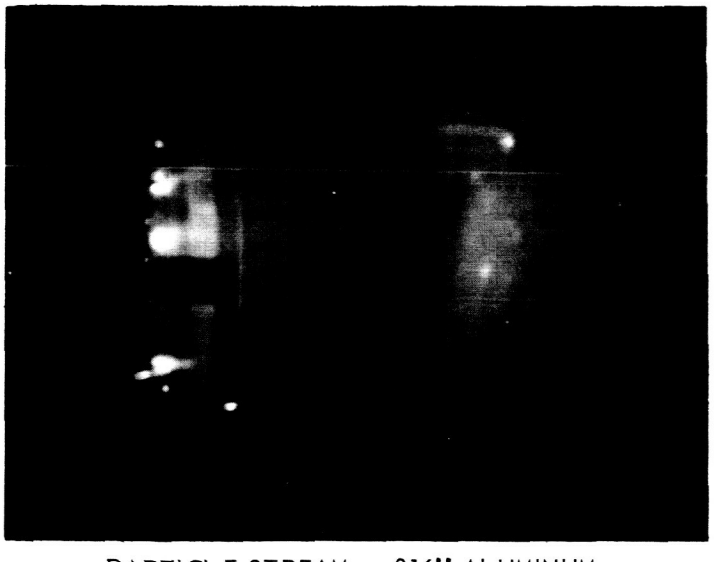
5.7.1 Heat Characteristics Produced with Meteoroid Penetration

Probably the most injurious form of oxidative energy produced in target penetration was found to be the heat produced by the oxidation of the displaced target materials. Aluminum oxide and molten aluminum from the target were generally found on the test specimens. Results of x-ray diffraction analysis of the aluminum oxide deposits using the cobalt tube method indicated the presence of both the gamma and alpha metallurgical forms. This indicates that a temperature of at least 1000 degree C. existed in the energy release area. Oxidation is seen to extend from the target out six to eight inches when the test chamber contained a 50 percent oxygen environment as shown in Figure 6. The cone of release was less when lower concentrations of oxygen were used, also shown in Figure 6. The presence of condensed aluminum vapor and molten aluminum on the specimens gives evidence of at least 2450 degrees C. at the target wall. The greater proportion of gamma to the alpha forms of aluminum oxide leads to the conclusion, however, that the high temperature produced by oxidation is extremely transient.

Fastax camera records of the tests provided an indication of high energy release early in these tests. The good appearance of the test specimens which had been located below the target did not lend support to the presence of such high temperatures. To determine why so little injury results under this condition, two tests were conducted to determine the ignition properties of rats' hair. Test expense was kept at a minimum by performing them in the test chamber using a type of pyrotechnic device called a match squib. This squib was taped to the back of a dead specimen. A cabin atmosphere of 100 percent oxygen at 5 psia was established, and the



PARTICLE STREAM – .016" TITANIUM



PARTICLE STREAM – .016" ALUMINUM

FIGURE 6. PARTICLE STREAM AND ENERGY RELEASE UPON PENETRATION OF TARGET WALL USING PARTICLE OF 60 GRIT SILICON CARBIDE PELLETS (SHEET 1 OF 2)

ENERGY RELEASE – AMBIENT ATMOSPHERE

ENERGY RELEASE – 50% OXYGEN
50% NITROGEN

FIGURE 6. PARTICLE STREAM AND ENERGY RELEASE PRODUCED BEHIND 0.020 INCH THICK TARGET BY PENETRATION OF 0.25 INCH DIAMETER GLASS PELLET (SHEET 2 OF 2)

squib electrically fired. It was found that only a small area of hair was burned. The match squib has a burning temperature of approximately 1090 degrees C. Further tests using an electrical heating element showed that rats' hair is not auto-igniting, and is, in fact, self-extinguishing even at atmospheric pressure and 100 percent oxygen. At 250 degrees C. the hair chars to carbon without flaming. The specimen was found to burn at 1090 degrees C. in this atmosphere. This data should be kept in mind when interpreting the results of this test. Unfortunately, these transient temperatures could not be measured with the instrumentation employed, (Appendix B). The duration and pattern of the oxidative heat would be of great assistance in determining the area of hazard produced in target penetration at the various test atmospheres.

The type and severity of injuries which would result if man was exposed to 3 to 4 milliseconds of such intense heat is not known. Flash fires which occur in gas filled rooms produce severe injuries or death in man, but in such accidents, the gas is usually inside the respiratory tract. Certainly if the oxidizing aluminum entered the trachea or lungs, catastrophic results would be produced. This heat surrounds the eyes, and therefore probably produces some irritation. However, the opacity of the cornea described in the pathological data occurred only when the rat had burned completely. Little permanent eye injury was noted when uniform specimen burning did not occur.

In summarizing, we find that intense heat is produced by oxidation of aluminum vapor behind the target on penetration. Based on the Fastax film data, this heat may be present for 15 milliseconds or slightly longer. Results of the pathological examination showed that the skin injury

produced is not severe unless the hair of the specimen is ignited. The extrapolation of these results to man is difficult, although certainly such exposure is an experience that one would urgently wish to avoid. The heat is believed to be produced by all penetrations, but the area covered and the duration is oxygen limited and varies primarily as a function of the size of the penetration. As with all energy release forms, except blast, heat is also related to the amount of oxidative material displaced by penetration, and the velocity of the displaced material at completion of penetration.

5.7.2 Light Characteristics Produced with Meteoroid Penetration

The threshold for permanent light induced retinal eye damage (flashblindness) for man has been established at approximately 270,000 ft. candles. Values approaching this were obtained in some of these tests. Post mortum examination, however, did not reveal any retinal burns in the test specimens. Certainly flashblindness was produced for a period in most tests, and at a level of severity that would have delayed crews in taking stock of damage and effecting repair. Light production in these tests has two sources, that produced at the target and that produced by the oxidation of vaporized target material. The latter, which occurred immediately around the eye, no doubt is the more damaging. Figure 6 shows the light produced by oxidation enveloping the eye of a specimen following penetration. The importance of high intensity light, when accompanied by the associated heat, may only be of academic importance when man is involved. It must be acknowledged, however, that examination of microscopic sections of the corneal epithelium did not reveal marked injury. Aluminum oxide deposits in the eye must have been a source of immediate irritation in any case. The results of gross examination of the test specimens immediately after the test must be viewed

with some caution. The shock produced by the noise of shaped charge detonation could not be separated from other stresses produced only by the experimental variables. The results of the simple tests for vision function described in the Procedure, were always influenced to a degree by the reduced responsiveness of the specimen. Control specimens obtained by firing charges without pellets were very much more alert, however, than those which had experienced target penetration. This may be interpreted as indicating that the energy released on penetration affects the responsiveness of the specimen.

Again, light intensity and heat production are related directly to the characteristics of the penetrations made in the target. These relationships will be discussed later in this section of the report.

5.7.3 Blast Pressure Characteristics

Blast pressure produced in hypervelocity penetration has its origin at the point of target plate penetration. It results from the sudden release of the kinetic energy of the penetrating particle behind the plate. Although oxidation of the metal vapor produced occurs at a violent rate, the pressure produced appears small compared to that resulting from initial particle penetration. The blast pressure recordings clearly show the peak pressure as a vertical spike on the memoscope. Other deflections of the trace are low in magnitude, probably produced by reflections of the initial blast wave. The duration of the peak blast pressure was found to be less than 10 microseconds. This very brief duration of overpressure does not produce significant lung injury. White discusses in detail the relationship between duration of peak pressure and mortality or injury in his report, "Biological Effects of Blast" (Reference 4). The LD_{50} for blast pressure was

found to be 36 psi for rats. Only a few pressures of this magnitude were obtained during this test. No blast deaths were produced, and blast injury was only tentatively identified. This is not surprising; there are many critical factors associated with the effects of blast. White described the drastic change in the rate of lethality produced in animals when moved only 0.5 inches relative to the incidence of the blast wave.

Since the point of target penetration could not be accurately controlled, the blast pressures recorded varied greatly between tests under the same conditions. This variation was nearly independent of oxygen concentration. The peak blast pressure was found to vary inversely with the distance between the point of target penetration and the pressure transducer. Since the pickup was located between the target and the test specimen, the rats were usually exposed to a lower pressure.

A lengthy discussion of blast injuries and the complex relationships which exist between the many physical variables does not seem pertinent here. The injurious effects of blast are marginal based on the results of autopsy and the physical data unfortunately does not lend itself to close analysis. The latter results primarily from the poor control of the point of particle impact.

5.7.4 Target Thickness, Particle Size and Penetration Velocity

The test results clearly indicate that the size of the penetration produced in the target plate was more important than the oxygen concentration in controlling the oxidative energy release phenomena; however, within a given range of penetration size, oxygen concentration had a marked effect on the level of energy released.

Under a given atmospheric condition small penetrations in the thin targets were found to produce little injury while small penetrations in thick targets often produced uniformly burned test specimens. This observation, presented in general terms, simply points up the fact that the amount of aluminum target metal displaced as a vapor is a critical parameter in establishing the intensity of the energy release produced inside the test chamber. The concentration of oxygen in the atmosphere in turn regulates the amount and rate of oxidation of the hot vaporized aluminum. These two variables are interdependent in producing the oxidative phenomena measured in these tests primarily in terms of the degree of injury produced. A critical oxygen level and penetration size for each thickness of target plate material could be identified with considerable accuracy if desired for a given impact at a given point on a target plate. An illustration of the hole sizes produced in representative thicknesses of targets by the various sized particles is given in Figure 7. Those which produced specimen burning are indicated. Hole area was determined using a "water clock" technique. A representative range of hole sizes were drilled in a series of unused target plates. The time required for a given quantity of water to pass through the holes was determined. The targets were then timed with an equal amount of water. This rather crude calibration was verified several times and found to be accurate within 15 percent. Some degree of compensation for the surface tension of water was provided by the wide range of hole sizes used in the standards.

Particle velocity is important in these tests only because of the relationship between impact velocity and the amount of target material displaced. Much work and many equations have been developed to predict

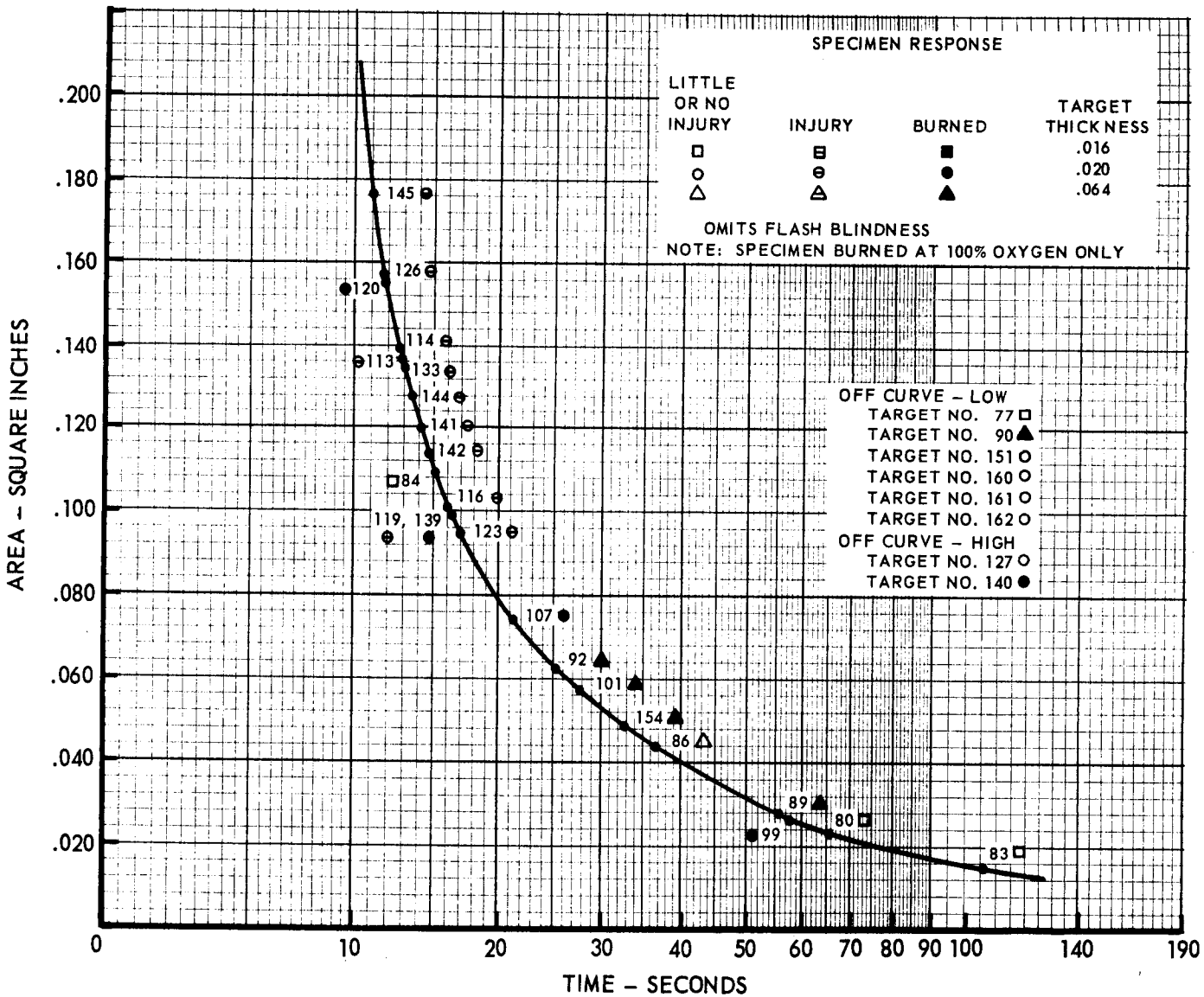


FIGURE 7. ANIMAL INJURY VS PENETRATION HOLE SIZE WITH TARGET THICKNESS INDICATED

the relationships between particle size and penetration depth or crater size. Palmer in Reference 2 (Cratering, Experiment and Theory) has developed an equation which predicts that particle penetration will occur in a plate which is not more than 1.5 times as thick as the crater depth produced in an infinite thickness of the same material.

5.7.5 Implications of Test Results

Based upon a review of the photographic records obtained during these tests, it should be clearly established that meteoroid penetration even without injury will result in considerable crew stress. Particularly in view of the widely accepted theory that these particles occur in showers. The light produced in penetration by even the smallest penetrating particle would generally be considered spectacular. Some spalling is sure to occur with resulting distraction and possible injury.

A wide range of injuries were produced in these tests. The most severe injuries resulted in immediate death by burning. These occurred at 100% oxygen concentrations. The mildest form of injury was temporary flash blindness which could not be detected in autopsy. These were produced using atmospheric air in the test chamber. Injuries of various intermediate degrees were, of course, also produced. Without implying an acceptable level of injury, the capabilities of a spacecraft crew can be considered.

Meteoroid penetration of the manned module of a spacecraft will, in itself, produce a requirement for immediate corrective action. Penetration of a full pressure suit of an extravehicular astronaut would impose an equally rigorous requirement for immediate repair on the part of the occupant. Ability to perform this repair establishes the degree of function required after exposure to meteoroid impact.

Clearly, then, very little disability can be tolerated in the event of meteoroid penetration. The results of this study indicates that the oxidative effects produced by hypervelocity penetration were reduced as a function of the decrease in oxygen concentration.

This was not the case for blast pressure, however, which was found to be related only to the size of the penetration produced. Since the highest blast pressure recorded in these tests was 38 psi, much below the injury threshold for man, this source of injury may be ignored for purposes of this analysis (Reference 4, "Biological Effects of Blast"). The holes produced did not result in an injurious rate of decompression, so the immediate effects of this hazard may also be ignored for particles in this size range. Depressurization rate data is presented in Figure 8.

As previously pointed out, then, maximum protection can be achieved by selecting an atmosphere which will support man, but provide the lowest practical concentration of oxygen in the man module. The results of this test indicate that a cabin atmosphere of 50 percent oxygen/50 percent nitrogen- 7 psia atmosphere already under consideration by the National Aeronautics and Space Administration best meets these criteria.

Tests conducted at this atmosphere indicate that injury will still occur depending upon the proximity of man to the point of penetration. Meteoroid penetrations of the size which produced specimen burning in these tests produced violent oxidation of the metal vapor over a cylindrical volume approximately 8 inches long and 4 inches in diameter. This volume was established based on photographic records. The temperature inside this oxidative zone will approach 1000 degrees C. for approximately 15 microseconds. Light intensity in the area of oxidation will approach 100,000 ft. candles.

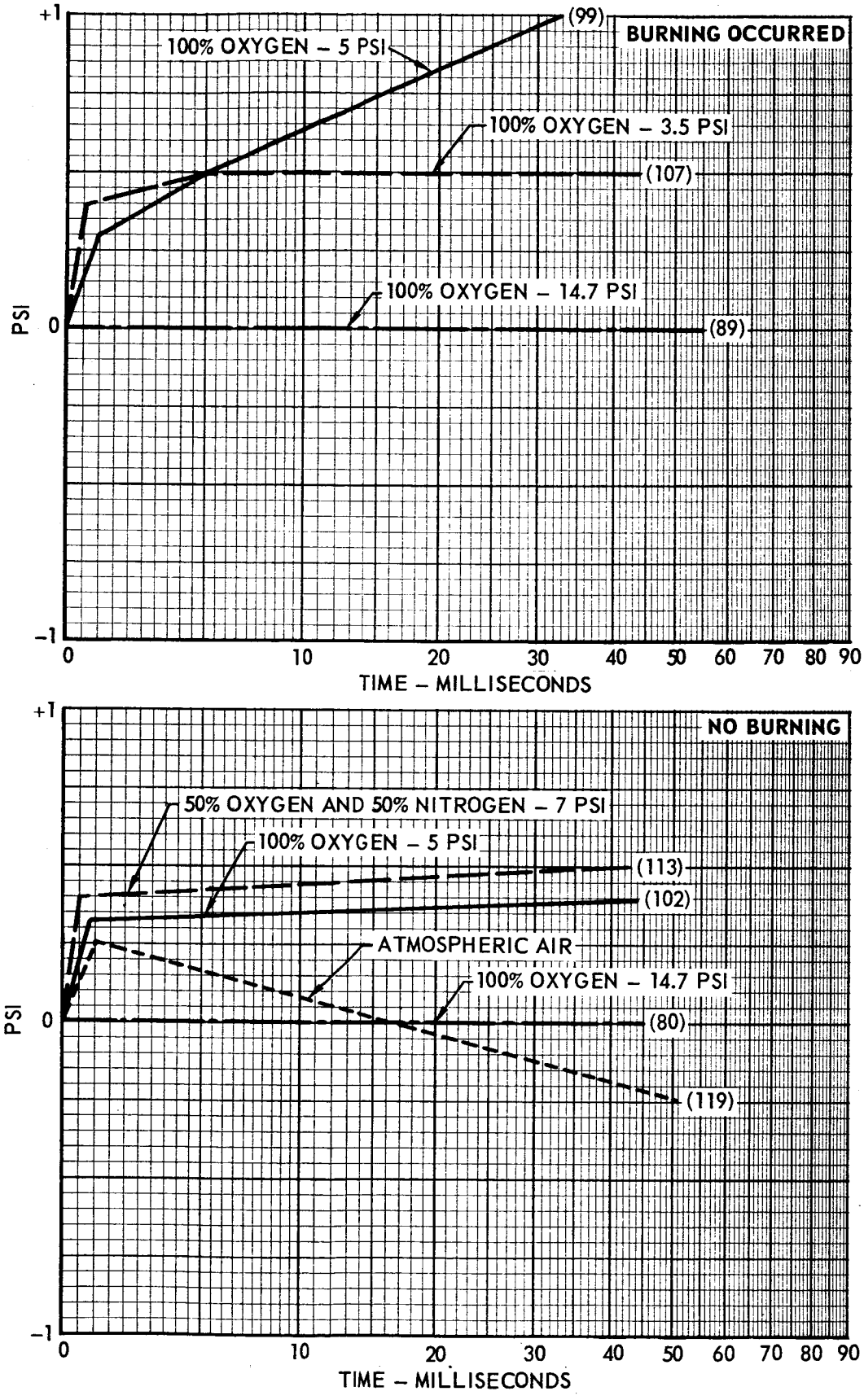


FIGURE 8. DEPRESSURIZATION OF 4 CU. FT. CHAMBER AFTER PENETRATION SHOWING PRESSURE VS TIME (SHEET 1 OF 2)

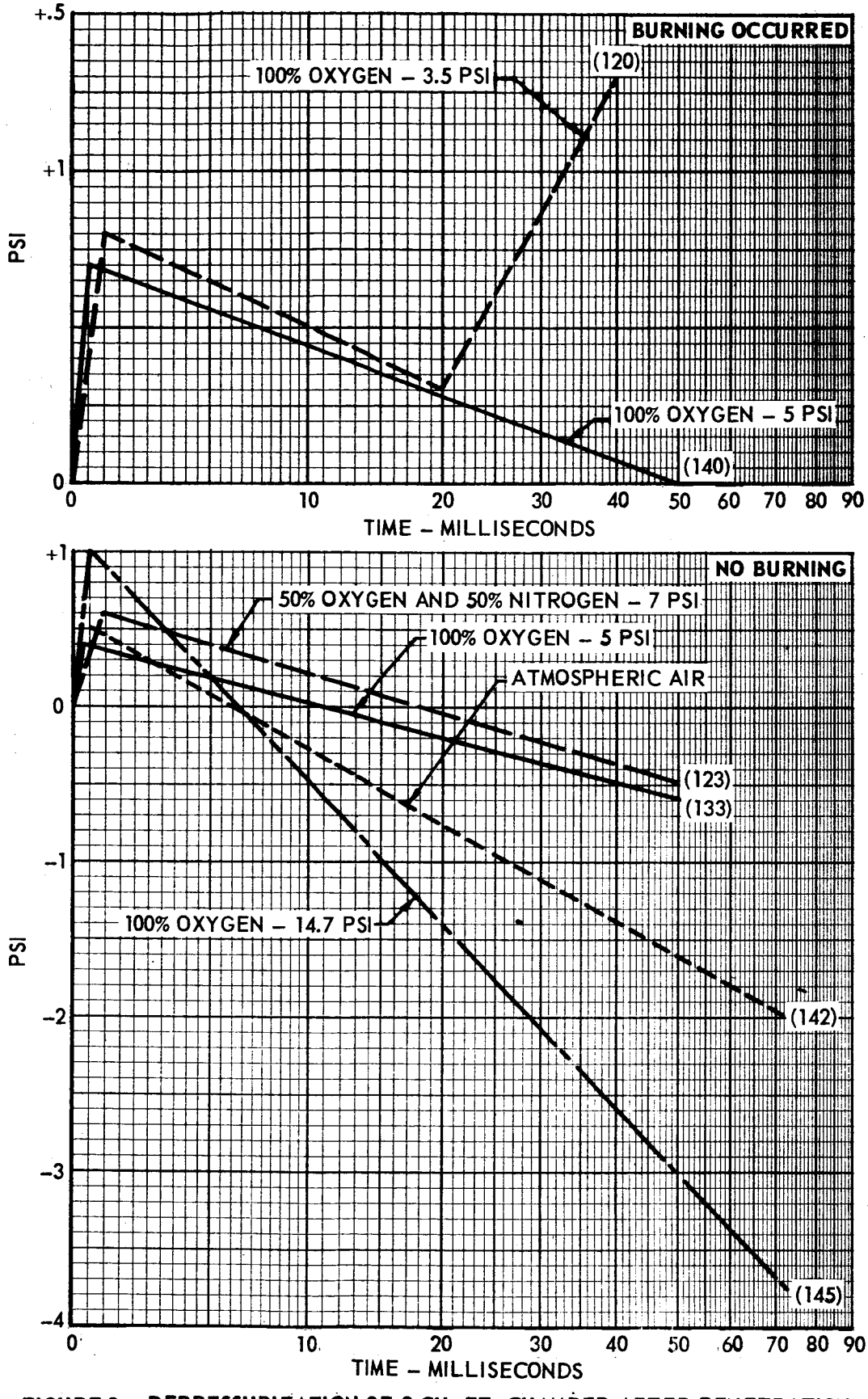


FIGURE 8. DEPRESSURIZATION OF 2 CU. FT. CHAMBER AFTER PENETRATION SHOWING PRESSURE VS TIME (SHEET 2 OF 2)

Many other factors are of course involved in the consideration of consequences of such an event. The interposition of equipment and stores between the crew and the point of penetration would afford good protection, but this makes the job of repair difficult and also ignores the effect on the equipment.

5.7.6 Frequency of Meteoroid Penetration

Determination of meteoroid flux, although under study for some time, is still far from complete. Information which will be collected within the next few years will shed much light on the adequacy of the simulation provided in these tests. This data may indeed rule out further concern about this problem, at least for lunar flights. In the interim, it seems appropriate to continue to pursue the problem of providing protection, particularly in view of proposed manned planetary flights with long flight times and in the vicinity of Asteroid belts.

5.7.7 Additional Physical Relationship Predicted by Test Data

A number of correlations between the characteristics of the accelerated particles, penetrations produced, and the recorded oxidative energy release phenomena are provided in Appendix D. These correlations include the degree of injury found to occur under the conditions presented, and may be used to predict the degree of injury or energy release which may be expected to occur in similar related events.

CONCLUSIONS AND RECOMMENDATIONS

6. Conclusions

The test data was analyzed to identify the effects of varying the gaseous environment on the incidence and degree of injury produced by simulated meteoroid penetration of a sealed chamber. The following conclusions are indicated by this study:

1. Oxidative energy release produced by hypervelocity particle penetration is localized within the area of distribution of vaporized wall material.

2. For a given wall thickness, the size of the penetration and the location of the test specimen relative to the point of penetration are the most significant variables in establishing the degree of severity of the injuries produced.

3. The oxygen partial pressure and concentration had a significant influence on the degree of test specimen injury produced by heat and light.

4. The location of the test specimen relative to the point of particle penetration was the most critical factor governing the degree of injury produced by blast overpressure.

5. Viewed from the standpoint of environmental protection in the event of meteoroid penetration, injury from heat and light exposure would be minimized by the use of a mixed breathing atmosphere of oxygen and nitrogen.

6.1 Recommendations

1. Investigate the practical methods of meteoroid shielding or multi-wall construction as a means of providing crew protection.

2. Conduct a more detailed test analysis of the incapacitating effects on the eye and "shock" injuries produced by small hypervelocity penetrations of simulated space vehicle.

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APPENDIX 'A'
SUMMARY OF PATHOLOGY

A-1.0 METHODS

Autopsies were performed on the test animals in the usual manner. Tissues were preserved in 10% formalin, microscopic sections prepared and stained with hematoxylin and eosin. Selected animals and organs were photographed grossly and photomicrographs were taken of certain abnormalities.

A-2.0 PARAMETERS OF ANIMAL INJURIES

A-2.1 Skin:

The most obvious abnormality encountered in the study represented changes of the skin. Considered insignificant was the deposition of particles of aluminum oxide which produced a discoloration of the fur but seemingly in no other way caused an abnormality of the skin. In addition there were a few animals in which shrapnel-like wounds were encountered in various loci of the body and were directly related to penetrations of the shield by the simulated micrometeorites. The ordinary secondary changes associated with such shrapnel-like injuries were found; namely, perforation of the skin with an associated disruption of the underlying structures and hemorrhage. In some instances the skin was not perforated but the dermal vessels so damaged by the striking object that focal petechiae resulted without penetration of the epidermis.

As a consequence of heat generated during the flash, there were varying degrees of burning of the hair and skin. In some of the more localized areas, the hair would present singeing of the terminal half or one-fourth of the hair without obvious damage to the underlying skin. In some instances this localized damage would progress to such singeing of the hair as to leave a stubble approximately 3 to 5 mm. in length, usually in a focal area measuring up to 10 to 14 mm. in diameter. The underlying skin was essentially normal.

Skin changes as a result of Nair consisted of the loss of the epithelium down to the basal cells, with congestion of dermal vessels and associated exudation.

The most devastating type of external injury to the skin represented a diffuse complete burning of the hair associated with charring, not only

of the hair, but more especially of thoseareas left unprotected by the hair; namely, eyelids, eyes, nose, ears, tail, and feet. On occasions the tongue was also burned. Microscopically, regardless of intensity of these diffuse carbonizing burns, all featured similar histologic changes with a coagulation necrosis of the epidermis and dermis which in most instances, extended to the subcutaneous tissue. In a few of the animals that demonstrated some degree of preservation of the proximal segments of the hair shafts, the cutaneous coagulation necrosis was indistinguishable from those animals in whom complete burning of the hair had occurred.

A-2.2 Eye:

Only in those animals in which marked diffuse cutaneous burning occurred were there noticeable changes within the cornea of the eye. This ordinarily assumed the proportions of focal loss of the epithelium, an intercellular edema between the epithelial cells and in some instances early necrosis of the superficial epithelium. In a few animals there was found particulate matter, presumably aluminum oxide, within the cornea and this material was birefringement. On careful examination of many of the eyes there was no evidence of a chorioretinal burn as has been observed following an atomic flash. The adjacent eyelid tissue served as a protection against the eyes from receiving a more severe type of damage.

A-2.3 Lungs:

Many of the sections of lungs demonstrated small focal areas of atelectasis in association with a prominence or dilatation of the alveolar ducts. This was seen also in the animal used as a control for Pressure Change. These changes were considered rather insignificant and perhaps not of a contributory nature to any physiological disturbance.

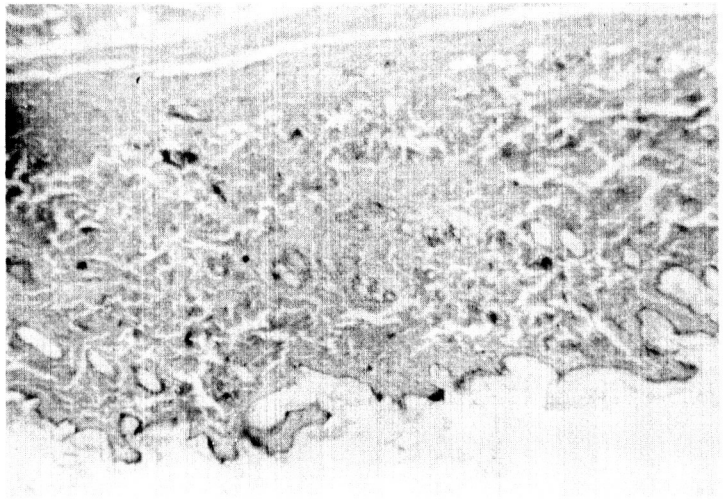
In most of the animals presenting a diffuse burning of the skin, there were more prominent pulmonary parenchymal changes. These consisted of pulmonary edema of varying severities, focal areas of pulmonary hemorrhage and mild to intense congestion. These changes are in keeping with pulmonary changes observed with blast and fire injuries. A few animals demonstrated birefringent particulate black matter within alveoli and alveolar walls, presumably aluminum oxide. The exact definition of the particulate matter should be further defined. This particulate matter was found in the lungs of only a few animals and therefore must be critical with respect to time, possibly of very short duration and occurring during the inspiration phase.

In a few animals the distention of the alveolar ducts bordered upon a centrilobular type of emphysema and it is difficult to determine whether or not this had any direct bearing upon either the pressure change or the blast effect, or whether this might represent variations in the normal histologic structure of some of the animals.

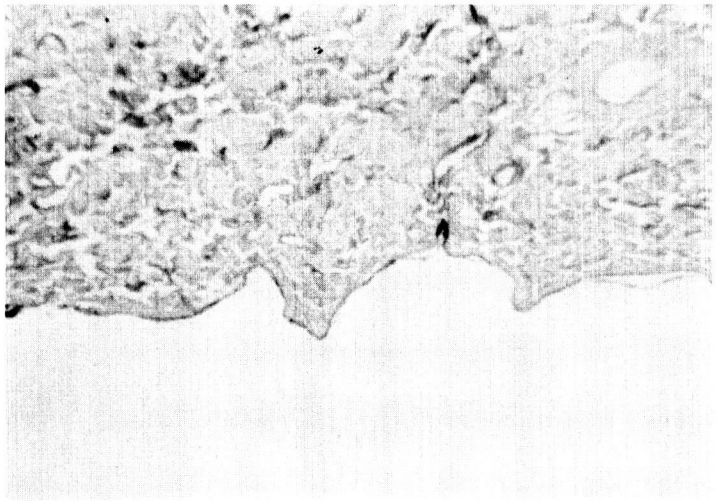
In a few animals there was concomitant disease, unrelated, but manifesting itself as a bronchopneumonia or a chronic inflammatory reaction within the bronchi.

A-2.4 Remaining Viscera:

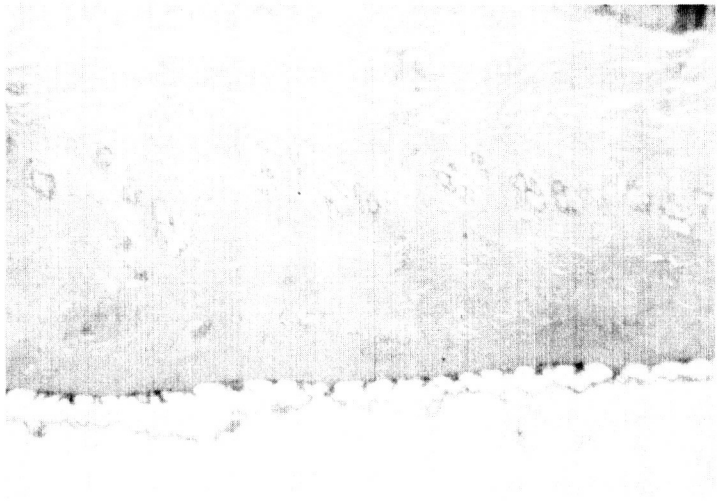
No significant abnormalities were observed in the remaining viscera.



NORMAL

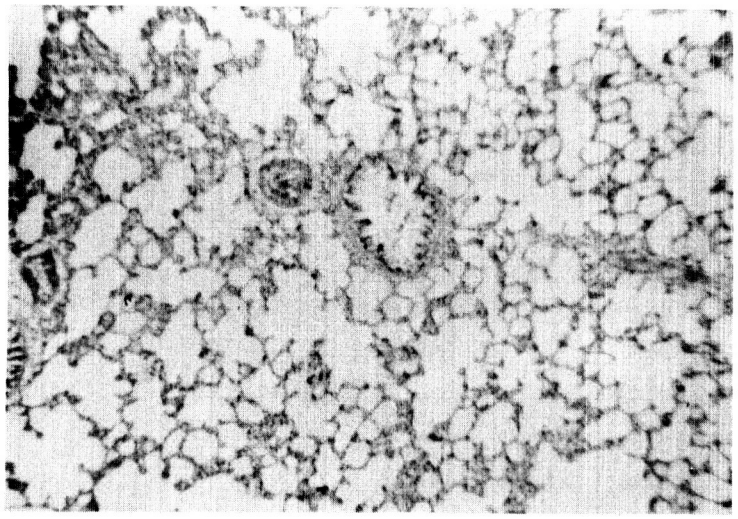


LOSS OF EPITHELIUM

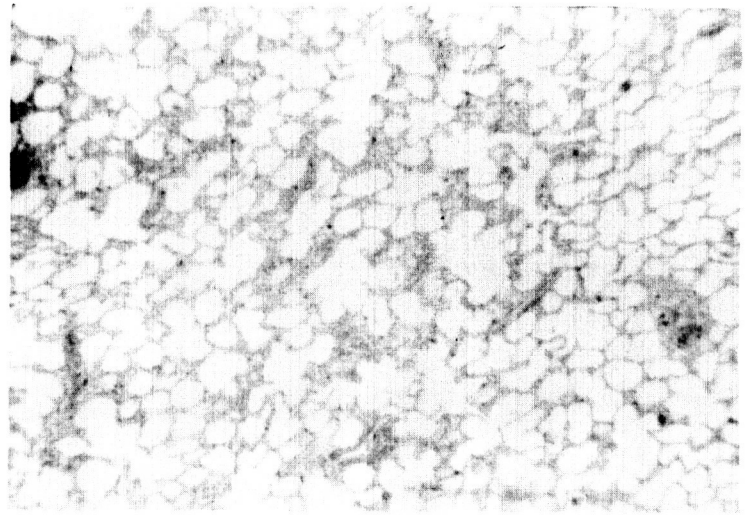


THIRD DEGREE BURN

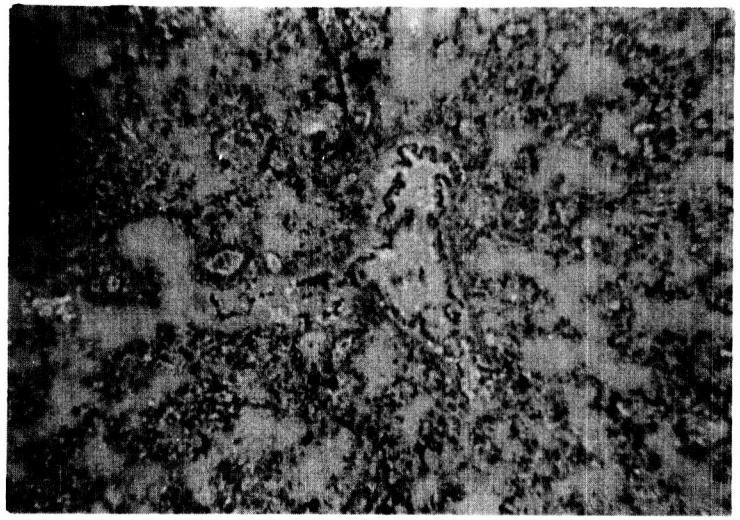
FIGURE A–1. PHOTOMICROGRAPHS OF SKIN SECTION SHOWING TYPICAL INJURIES PRODUCED BY TEST EXPOSURE



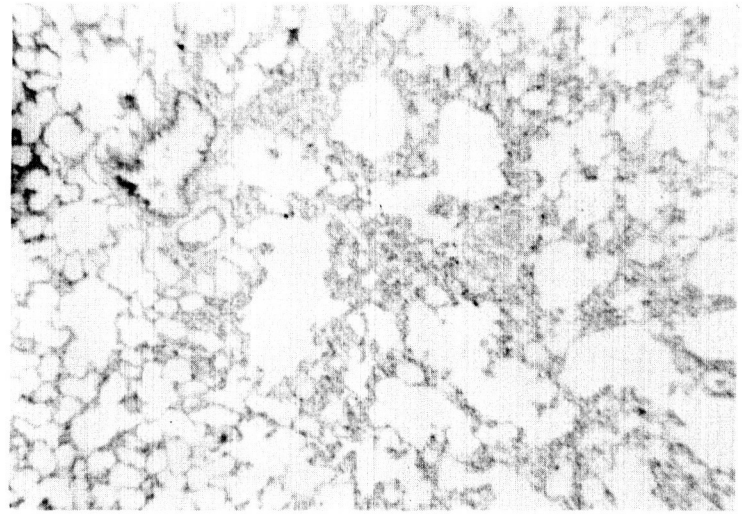
NORMAL.



INTENSE PULMONARY
CONGESTION



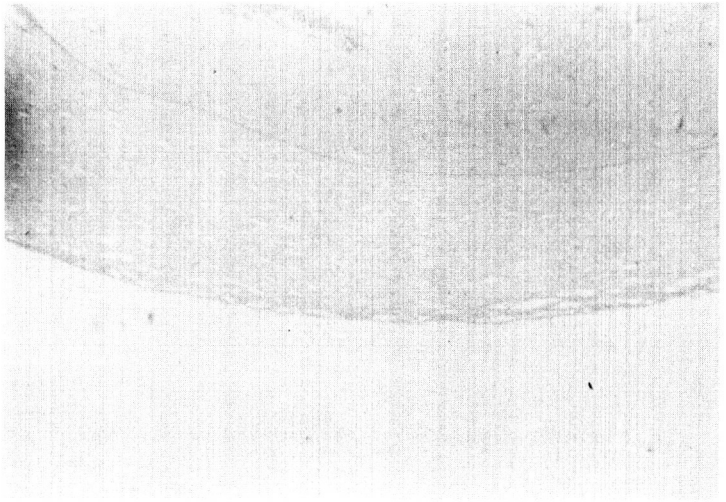
PULMONARY EDEMA
HEMORRHAGE – PARTICLES



FOCAL ATELECTASIS –
ALVEOLAR DUCT PROMINENCE

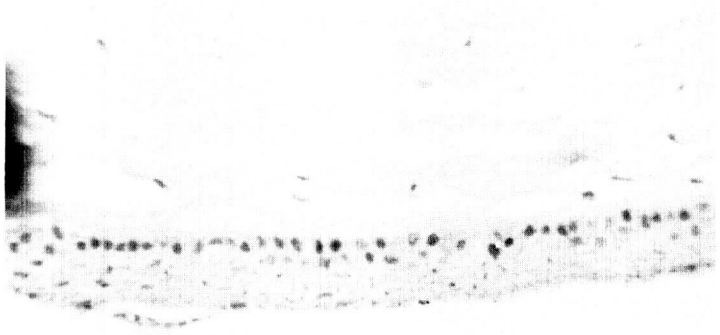
FIGURE A–2. PHOTOMICROGRAPHS OF LUNG SECTION SHOWING TYPICAL INJURIES PRODUCED BY TEST EXPOSURE

NORMAL



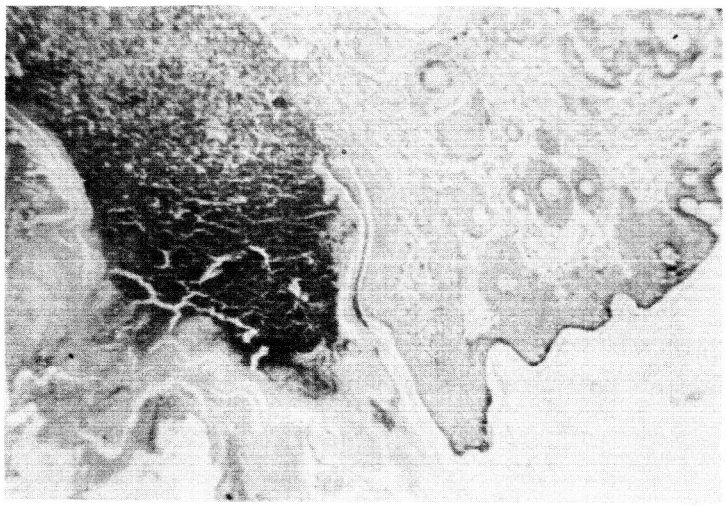
EPITHELIAL LOSS OF CORNEA

EPITHELIAL DISRUPTION OF CORNEA



PARTICULATE MATERIAL IN
EPITHELIUM OF CORNEA

FIGURE A–3. PHOTOMICROGRAPHS OF EYE SECTION SHOWING TYPICAL INJURIES PRODUCED BY TEST EXPOSURE

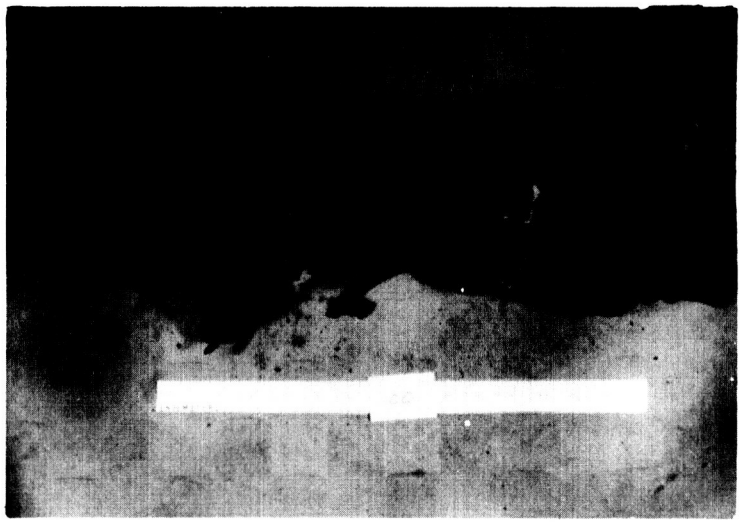


SHRAPNEL WOUNDS

SHRAPNEL WOUND WITH INFLAMATION

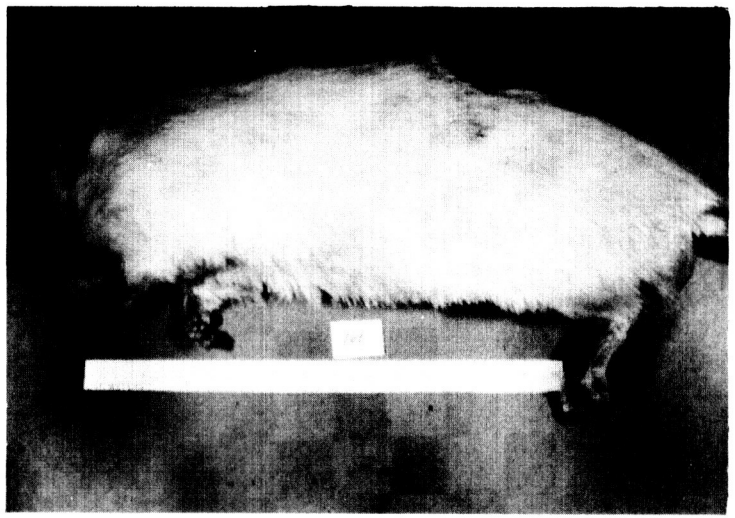
FIGURE A-4. PHOTOMICROGRAPHS OF SHRAPNEL WOUNDS PRODUCED BY SPALLED TARGET WALL MATERIAL OR PENETRATING PARTICLES

100% OXYGEN – 14.6 P.S.I.



100% OXYGEN – 5 P.S.I.

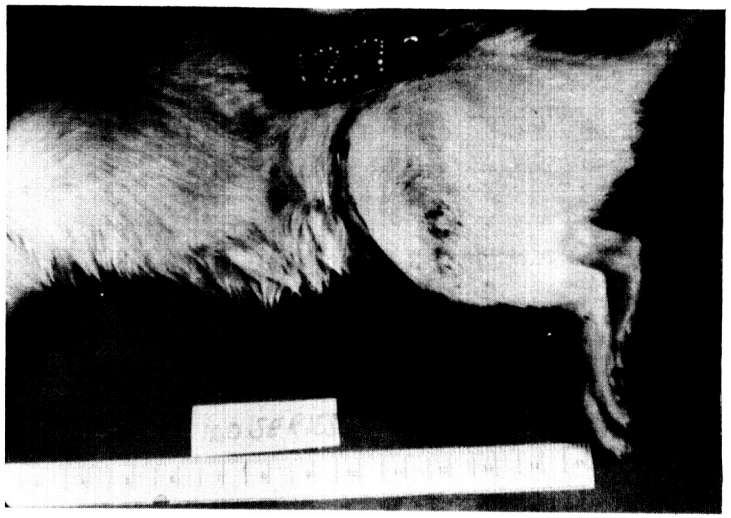
100% OXYGEN – 3.5 P.S.I.



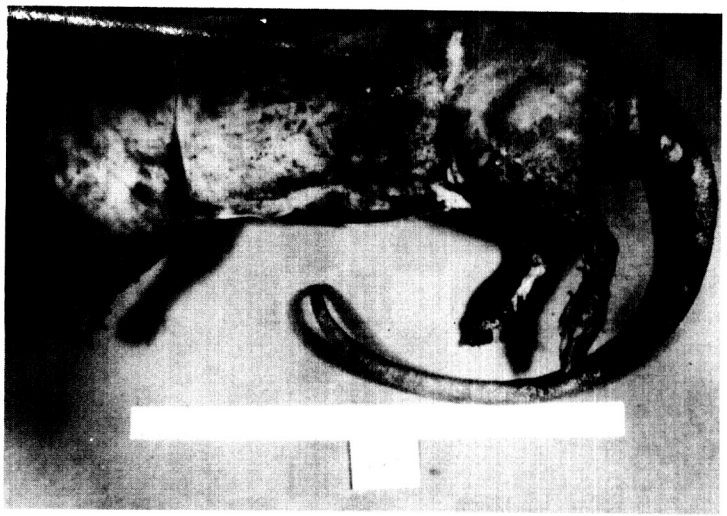
100% OXYGEN – 5 P.S.I.
(SCREENED TARGET)

FIGURE A–5. GROSS APPEARANCE OF SPECIMENS AFTER TEST UNDER VARIOUS CONDITIONS (SHEET 1 OF 2)

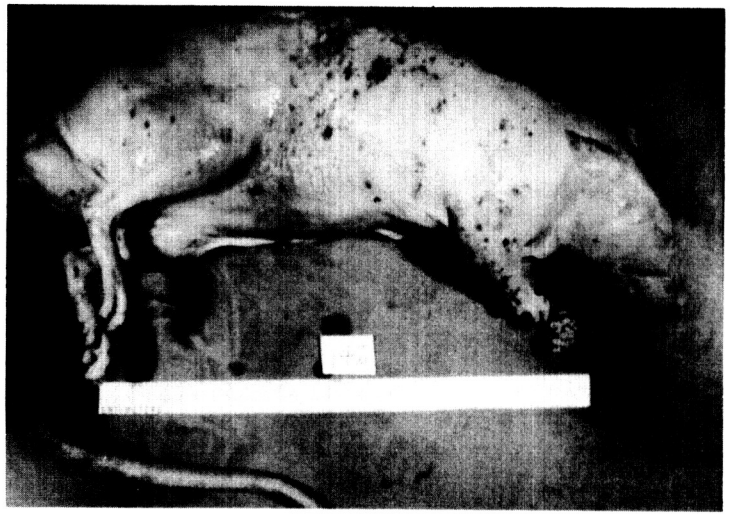
50% OXYGEN, 50% NITROGEN
7 P.S.I.



AMBIENT ATMOSPHERE

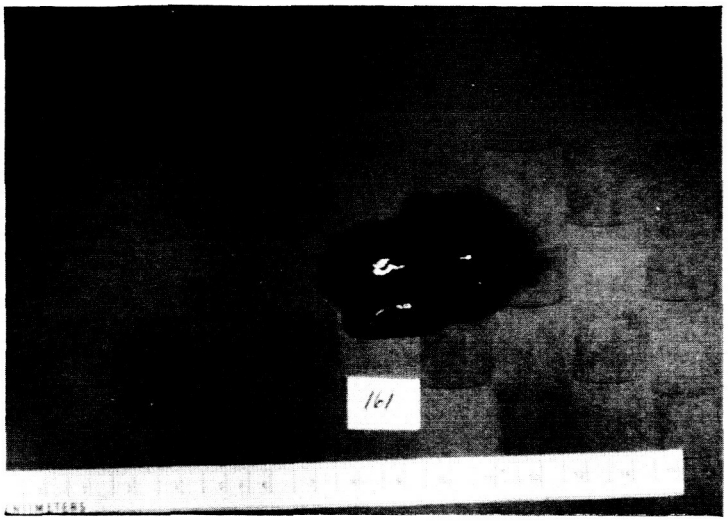


DEPILATED SERIES
(SHAVED)

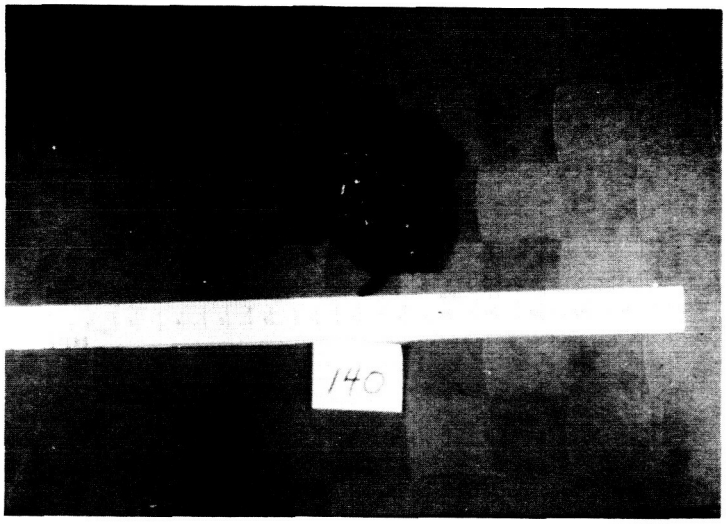


DEPILATED SERIES
(NAIR)

FIGURE A–5. GROSS APPEARANCE OF SPECIMEN AFTER TEST UNDER VARIOUS CONDITIONS (SHEET 2 OF 2)



NORMAL



INJURED – CONGESTION, PULMONARY EDEMA, PULMONARY HEMORRHAGE, EMPHYSEMA (SWELLING) PRODUCED IN RAT LUNG BY TEST CONDITION

FIGURE A–6. GROSS NORMAL AND TYPICAL LUNG INJURY AFTER HYPERVELOCITY PENETRATION OF TARGET WALL

A-2.5 ANIMAL AUTOPSY PROTOCOLS

Animal Number 73

Gross Examination:

Although the fur over the back demonstrated particulate aluminum oxide deposition, the gross pathological examination, externally and of the internal viscera, was normal.

Microscopic Examination:

Lungs: Minimal focal areas of atelectasis with scattered small foci of hemorrhage are observed throughout the pulmonary parenchyma.

Heart, Spleen, Liver, and Kidney: No significant abnormalities.

Animal Number 74

Gross Examination:

The fur over the back demonstrates an intense particulate deposition of aluminum oxide, but no other gross abnormalities are observed either of the skin or of the internal viscera.

No gross photographs taken.

Microscopic Examination:

Lungs: In addition to scattered small focal areas of atelectasis, the alveolar ducts are noted to be prominent bordering upon a sufficient amount of dilatation to entertain the diagnosis of centrilobular emphysema.

Heart, Spleen, Liver, Kidney and Testes: No significant abnormalities.

Animal Number 74 (continued)

Photomicrographs are taken to demonstrate the normal lung histology presenting a bronchus, blood vessel, and normal alveolar ducts together with alveoli.

The second photomicrographs demonstrates the changes of focal atelectasis and associated centrilobular alveolar duct prominence.

Animal Number 75

Gross Examination:

In addition to the fur over the back demonstrating the particulate deposition of aluminum oxide, there is crusted blood about the external nares. No other abnormalities are noted on gross examination.

No gross photographs taken.

Microscopic Examination:

Lungs: Demonstrates scattered focal areas of atelectasis associated with a minimal interstitial thickening and a focal peribronchial inflammatory response. The centrilobular alveolar ducts demonstrate again focal areas of prominence bordering upon an emphysematous change.

Liver, Heart, GI Tract, Testes, Eye: No significant abnormalities.

Photomicrographs of normal cornea.

Animal Number 76

Gross Examination:

The fur demonstrates the deposition of aluminum oxide particles, but otherwise the gross examination demonstrates no pathologic abnormalities.

Microscopic Examination:

Lungs: Focal areas of atelectasis are noted.

Heart, Spleen, Pancreas, Kidney and Liver: No significant abnormalities.

No photomicrographs taken.

Animal Number 84

Gross Examination:

The fur over the head demonstrates deposition of aluminum oxide particles, but the gross pathological examination externally and of the internal viscera is normal.

No gross photographs taken.

Microscopic Examination:

Lungs: Scattered focal areas of atelectasis are intermingled with a concomitant moderate bronchopneumonia which has produced intense congestion of the vessels.

Heart, Kidney, Testes, Adrenal, Tongue, GI Tract, Liver, Spleen, and Eye: No significant abnormalities.

No photomicrographs taken.

Animal Number 85

Gross Examination:

In addition to the deposition of aluminum oxide particles on the fur there is a focal area about the scapula measuring

Animal Number 85 (continued)

15 mm. in diameter which presented the characteristic change of the fur when exposed to heat, namely singeing. No other gross abnormalities were observed either externally or internally.

No gross photographs taken.

Microscopic Examination:

Lungs: Focal areas of atelectasis associated with distention of the alveolar ducts presenting a pattern bordering upon centrilobular emphysema as observed in association with slight congestion.

Heart, Liver, Spleen, GI Tract, Kidney, Testes, and Eye: No significant abnormalities.

No photomicrographs taken.

Animal Number 86

Gross Examination:

Aluminum oxide particulate deposition was noted about the fur and in addition, there was a small focal area of singeing of the fur noted over the left scapular region. No other abnormalities on external or internal examination were observed.

No gross photographs taken.

Microscopic Examination:

Lungs: The lung demonstrates an intense pulmonary edema associated with focal areas of hemorrhage and extremely prominent centrilobular alveolar ducts bordering on a traumatic type of emphysema. Scattered throughout the walls of the alveoli are black small particles which are birefringent.

Animal Number 86 (continued)

Heart, Liver, Spleen, Kidney: No significant abnormalities.

Photomicrographs are taken of the lungs demonstrating pulmonary edema, hemorrhage and congestion, and are also taken with polarized light to demonstrate the birefringent black particles presumably representing aluminum oxide inhalation.

Animal Number 87

Gross Examination:

The skin is uniformly burned to the epidermis and structures not protected by fur, such as the eyelids, ears, nose, and tail, and feet, demonstate an intense charring effect. The eyes show an opacifying change within the cornea. The tongue similarly demonstrates burning effect. Protected areas represented the only places where the animal was not burned and these protected areas corresponded to the places where the animal tie-down was accomplished.

Gross photographs are taken of the animal externally.

The only visceral change represented the lungs which presented a pulmonary edema grossly with focal areas of hemorrhage.

Gross photographs were taken.

Microscopic Examination:

Lungs: The lungs demonstrated a pulmonary edema together with congestion and focal areas of early acute inflammatory response.

Animal Number 87 (continued)

Skin: The skin sections, while improperly embedded, do demonstrate intense third degree burn producing a coagulation necrosis of the epidermis through the dermis to the junction of the subcutaneous tissue.

Heart, Liver, Kidney, and Adrenal: No significant abnormalities.

No photomicrographs are taken.

Animal Number 89

Gross Examination:

External examination demonstrates that the fur is uniformly burned to the epidermis and structures not protected by the fur such as the eyelids, ears, nose, tail, and feet demonstrate an intense charring effect. The eyes show an opacifying change within the cornea. Areas failing to demonstrate burning of the skin are those places where animal tie-down was accomplished.

Internal examination showed the lungs to be heavier than normal, dark, and hemorrhagic.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: Microscopic examination demonstrates an intense pulmonary edema associated with marked congestion and focal areas of hemorrhage with some areas of traumatic rupture of not only the centrilobular alveolar ducts, but also the terminal bronchioles. Black birefringent particulate matter is again observed.

Animal Number 89 (continued)

Skin: Third degree thermal burns are noted of the skin producing a coagulation necrosis of the epidermis and the dermis down to the lower segment of the dermis in the region of its junction with the subcutaneous tissue.

Heart, Kidney, and Liver: No significant abnormalities.

Photomicrographs are taken of the lung to demonstrate the pulmonary edema, focal hemorrhage, and the particulate matter. In addition, photomicrographs of the skin are taken to demonstrate the normal, uninvolved area (due to the protection of the tie-down) and the burned area, showing the coagulation necrosis of epidermis and dermis.

Animal Number 90

Gross Examination:

The fur is uniformly burned to the epidermis and the structures not protected by fur, such as the eyelids, ears, nose, tail, and feet demonstrate an intense charring effect. The eyes show an opacifying change within the cornea. The protected areas of the animal fail to show evidence of burning.

The only internal visceral change is that of the lungs which show a uniform hemorrhagic discoloration.

Microscopic Examination:

Lungs: The lungs again show the intense pulmonary edema associated with focal areas of hemorrhage and congestion.

Animal Number 90 (continued)

Skin: The skin demonstrates an intense coagulation necrosis of a third degree burn extending from the epidermis through the dermis to the junction of the dermis with the subcutaneous tissue.

Heart, Spleen, Liver, and Kidney: No significant abnormalities.

No photomicrographs taken.

Animal Number 92

Gross Examination:

The fur demonstrates a uniform burning to the epidermis with structures unprotected by fur showing a more intense charring effect. The eyes show an opacifying change within the cornea. Smaller protected areas of the skin being unburned are the regions which represented the animal tie-down. The tongue shows a marked amount of burning.

The lungs show a focal and moderate amount of hemorrhage.

Gross photographs are taken of both the animal and lungs.

Miscroscopic Examination:

Lungs: Microscopic examination shows an intense pulmonary edema and congestion, associated with focal areas of hemorrhage.

Skin: The skin shows third degee thermal burns involving the epidermis and dermis down to the level of the subcutaneous tissue by intense coagulation necrosis.

Tongue: The tongue shows thermal burns.

Animal Number 92 (continued)

Heart, Kidney, and Liver: No significant abnormalities.

No photomicrographs taken.

Animal Number 94

Gross Examination:

The fur is uniformly burned to the epidermis with the exception of those areas in which the tie-down afforded the animal protection. Those areas unprotected by fur such as the eyelids, ears, nose, tail, and feet, demonstrated an intense charring effect. The eyes demonstrate an opacifying change within the cornea. The tongue similarly demonstrates burning.

The lungs show a diffuse hemorrhagic change.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: An intense congestion, pulmonary edema, and focal areas of hemorrhage are noted within the pulmonary parenchyma and an extreme distention of the alveolar ducts bordering on an emphysema is observed.

Skin: Although the skin is not properly oriented in sectioning there is a third degree thermal burn extending to the subcutaneous tissue as observed by the coagulation necrosis of the fat.

Heart, Liver, Kidney, GI Tract: No significant abnormalities.

No photomicrographs taken.

Animal Number 96

Gross Examination:

A moderate amount of aluminum oxide particles are scattered about the fur of the back in between the region of the shoulders. Examination of the rest of the skin fails to show any abnormalities.

Internal examination shows the lungs to be essentially normal with small scattered focal areas of hemorrhage.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: Minimal focal areas of atelectasis, hemorrhage and congestion are observed and in some areas there is a distention of the alveolar ducts bordering on a centrilobular emphysema.

Heart, Liver, Spleen, and Kidney: No significant abnormalities.

No photomicrographs taken.

Animal Number 99

Gross Examination:

The fur is uniformly burned to the epidermis and the areas of animal tie-down have afforded only a moderate amount of protection. Those areas in which there is a lack of protection by fur, such as the eyelids, ears, nose, tail, and feet, the thermal effect had progressed to charring. The eyes demonstrated an opacifying change within the cornea. The tongue similarly demonstrated a thermal change.

The lungs show a diffuse hemorrhagic change.

Gross photographs are taken of both the animal and lungs.

Animal Number 99 (continued)

Microscopic Examination:

Lungs: Pulmonary congestion, edema, and focal areas of hemorrhage are observed within the pulmonary parenchyma.

Skin: Third degree thermal burns characterized by coagulation necrosis involving the epidermis and dermis extending to the subcutaneous tissue is observed.

Kidney, Liver, and Heart: No significant abnormalities.

No photomicrographs taken.

Animal Number 100

Gross Examination:

The fur is uniformly burned down to the skin except in those areas where protection was afforded by the animal tie-down apparatus. Those areas not protected by fur, such as the eyelids, ears, nose, tail, and feet demonstrated an intense charring effect. The eyes show an opacifying change within the cornea. The tongue similarly demonstrated burning.

The lungs are dark and hemorrhagic.

Gross photographs are taken of both the animal and lungs.

Miscroscopic Examination:

Lungs: An intense congestion, edema, and focal areas of hemorrhage are present associated with a modest amount of centrilobular distention of the alveolar ducts.

Skin: Third degree burn of the skin is observed characterized by an intense necrosis of the epidermis and dermis extending down to the subcutaneous tissue.

Animal Number 100 (continued)

Heart, Kidney, and Liver: No significant abnormalities.

No photomicrographs taken.

Animal Number 101

Gross Examination:

Although the fur again demonstrates an intense burning effect, there is a small zone of comparatively normal fur between the epidermis and the terminal burned segments of the fur. This protected zone is 3 mm. in length. Those areas unprotected by fur, such as the eyelids, ears, nose, tail and feet, demonstrate an intense charring effect. The eyes also show an opacifying change within the cornea. The tongue is burned.

The lungs are focally hemorrhagic with intervening areas of comparatively normal pulmonary tissue.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: Lungs demonstrate a moderate degree of pulmonary edema and congestion with focal areas of hemorrhage and a prominent distention of the alveolar ducts and some alveoli, producing an emphysematous change.

Skin: The skin demonstrates third degree thermal burn involving coagulation necrosis of the epidermis down to the subcutaneous tissue.

Heart, Kidney, Spleen, and Liver: No significant abnormalities.

Animal Number 101 (continued)

Photomicrographs are taken, demonstrating the moderate pulmonary changes of edema, congestion, and alveolar ductal distention.

Animal Number 102

Gross Examination:

There is a large region of aluminum oxide particle deposition over the back especially in the left scapular area. No other abnormalities are noted externally or upon examination of the viscera, with the exception of the lungs which demonstrate a diffuse reddish change punctuated by focal areas of hemorrhage.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: Demonstrates an intense congestion with a minimal amount of edema and focal areas of hemorrhage. Some distention of the alveolar ducts is observed.

Heart, Kidney, Liver, and Spleen: No significant abnormalities.

Photomicrographs are taken of the pulmonary parenchyma to demonstrate the intense congestion.

Animal Number 103

Gross Examination:

An intense discoloration due to the deposition of aluminum oxide particles is observed about the upper segment of the back, particularly in the region of the left scapula. The lungs show focal areas of hemorrhage of a minimal nature.

Gross photographs are taken of both the animal and lungs.

Animal Number 103 (continued)

Microscopic Examination:

Lungs: An intense congestion, minimal pulmonary edema, and focal hemorrhage is observed within the pulmonary parenchyma.

Heart, Liver, Kidney and Spleen: No significant abnormalities.

No photomicrographs taken.

Animal Number 104

Gross Examination:

Considerable discoloration over the upper segment of the back is noted due to the aluminum oxide particles within the fur. The lungs show a pink color with minimal areas of focal hemorrhage.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: A moderate to intense congestion with minimal pulmonary edema and minimal focal areas of hemorrhage are observed. An increase in the diameter of the centrilobular alveoli is observed bordering upon emphysema.

Heart, Liver, Spleen and Kidney: No significant abnormalities.

No photomicrographs taken.

Animal Number 107

Gross Examination:

The fur is uniformly burned to the skin and in those areas protected by animal tie-down the fur is not burned. In those areas not protected by fur, such as eyelids, ears, nose, tail, and feet, there is an intense charring effect. The eyes demonstrate an opacifying change within the cornea. The tongue is burned.

The lungs are dark and hemorrhagic.

Gross photographs are taken of both the animal and lungs.

Animal Number 107 (Continued)

Microscopic Examination:

Lungs: An intense pulmonary congestion and edema is observed.

Eyes: Thermal burns are noted of the eyelid and of the cornea producing desquamation of the epithelial cells covering the cornea.

Skin: Third degree thermal burns of the skin is observed with coagulation necrosis involving the epidermis and dermis.

Heart, Kidney, Liver and Spleen: No significant abnormalities.

Photomicrographs are taken of the eye and the cornea to demonstrate the charring and desquamating epithelial effect.

Animal Number 109

Gross Examination:

The hair is uniformly burned to the epidermis and only in those regions protected by the animal tie-down is any hair preserved. Those areas unprotected by hair, such as the eyelids, ears, nose, tail, and feet, demonstrate an intense charring effect. The eyes show an opacifying change within the cornea.

The lungs are uniformly dark and hemorrhagic.

Gross photographs are taken of both the animal and lungs.

Animal Number 109 (Continued)

Microscopic Examination:

Lungs: An intense congestion and edema are observed.

Eyes: The eye is sectioned in the wrong plane for a proper orientation but is normal, that portion which is examined, and no retnal abnormalities are observed.

Skin: Third degree thermal burns are seen with coagulation necrosis of the epidermis and full thickness of the dermis to the subcutaneous tissue.

Heart, Kidney, Liver, GI Tract: No significant abnormalities.

No photomicrographs taken.

Animal Number 110

Gross Examination:

The fur is uniformly burned to the skin and the only areas uninvolved are those areas protected by the animal tie-down. The structures having no protection by fur such as the eyelids, ears, nose, tail, and feet demonstrate an intense charring effect.

The lungs are focally hemorrhagic.

Gross photographs are taken of both the animal and lungs.

Animal Number 110 (Continued)

Microscopic Examination:

Lungs: An intense congestion, pulmonary edema, associated with some atelectasis and distention of the alveolar ducts is observed.

Eyes: Although the section of the eye presents a wrong plane of embedding, the retina shows no abnormalities.

Skin: The epidermis and dermis demonstrate an intense coagulation necrosis extending to the subcutaneous tissue.

Heart, Kidney, Spleen, Liver, and GI Tract: No significant abnormalities.

No photomicrographs taken.

Animal Number 111 (Series)

Gross Examination:

All animals demonstrate a superficial focal area of singeing of the hair unaccompanied by an intense diffuse burning. This focal area of singeing varies from 8 to 12 mm. in greatest diameter and produces a loss of hair down to the region of the skin, usually leaving a stubble of about 4 to 6 mm.

The lungs and other viscera are normal.

Gross photographs of the animals are taken.

Microscopic Examination:

Lungs: Focal areas of atelectasis, a minimal focal peribronchial inflammatory reaction and a mild distention of the alveolar ducts is observed.

Animal Number 111 (Series) (Continued)

Eyes: No significant abnormalities.

Heart, Kidney, Liver, GI Tract, Spleen, and Adrenal: No significant abnormalities.

No photomicrographs taken.

Animal Number 115

Gross Examination:

In the region of the left ear there is superficial singeing of the hair and there is an associated shrapnel wound of the free portion of the ear. This area of singeing measures 10 x 8 mm. and is definitely separate from the shrapnel wound of the ear.

The lungs are grossly normal. No other visceral abnormalities are observed.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: A minimal focal atelectasis and mild congestion is observed with a peribronchial inflammatory reaction of an unrelated nature.

Skin: An acute and chronic inflammatory reaction is present about the sinus tract of the shrapnel wound in the region of the ear.

Heart, Spleen, GI Tract, Liver and Kidney: No significant abnormalities.

Photomicrographs are taken of the shrapnel wound involving the ear.

Animal Number 120

Gross Examination:

The hair is diffusely but patchily burned over the body leaving a zone of unburned hair varying from 3 to 6 mm. out to the base of each hair shaft. The areas protected by animal tie-down are unburned. Although there is charring of the areas unprotected by hair, this is less noticable than in the other animals.

The lungs are dark, but no other visceral changes are observed.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: A moderate congestion and pulmonary edema are present.

Eyes: A focal patchy loss of the covering epithelium is observed.

Skin: Third degree thermal burns with necrosis of the epidermis and dermis are present.

Heart, Liver, Kidney, Spleen, and Testes: No significant abnormalities.

No photomicrographs taken.

Animal Number 121

Gross Examination:

The hair is diffusely but patchily burned leaving an uninvolved area in those areas where the animal tie-down protected the hair. At the base of each of the burned hair

Animal Number 121 (Continued)

shafts, there is a normal zone of hair which varies from 3 to 5 mm. in length. Those areas unprotected by hair show some charring, but to a less degree than previously noted on other animals.

The lungs are dark but no other visceral abnormalities are observed.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: A moderate congestion and edema with a focal peribronchial inflammatory reaction is observed.

Eyes: Superficial corneal loss of the covering epithelium is observed in a patchy manner, this change extends to involve the adjacent eyelid.

Skin: Third degree thermal burns of the upper and mid-segment of the dermis and epidermis are observed.

Heart, Testes, Liver, Kidney, Spleen and GI Tract: No significant abnormalities.

Photomicrographs are taken of the cornea of the eye demonstrating the loss of the epithelial covering.

Animal Number 122

Gross Examination:

In addition to the deposition of particles of aluminum oxide there are focal areas of singeing varying up to 14 mm. in diameter which have progressed to the base of the hair shafts and produce superficial epidermis change.

Animal Number 122 (Continued)

The viscera show no abnormalities.

Gross photographs are taken of the animal.

Microscopic Examination:

Lungs: Focal atelectasis and congestion are observed.

Skin: Superficial hemorrhage is observed as a result of the superficial type of thermal response. This would be perhaps a first degree burn and represents a manifestation of erythema.

Eyes: No significant abnormalities.

Heart, Liver, Kidney, Spleen and Testes: No significant abnormalities.

No photomicrographs taken.

Animal Number 127

Gross Examination:

The left thigh shows a moderate shrapnel injury with other areas about the body of focal singeing of the hair, but no diffuse burning. The base of many of the hair shafts, in the area of singeing, are normal.

Lungs and other viscera are normal.

Gross photographs are taken.

Microscopic Examination:

Lungs: Focal atelectasis and congestion are observed.

Eyes: No significant abnormalities.

Skin: A superficial inflammatory reaction is observed, but no definite indication of thermal burns is present.

Animal Number 127 (Continued)

Heart, Kidney, Spleen, Liver and Testes: No significant abnormalities.

No photomicrographs taken.

Animal Number 129

Gross Examination:

The hair demonstrates a uniform but patchy degree of burning with the base of each of the burned hair shafts being comparatively normal for a zone of 3 to 5 mm. Areas of completely normal hair represent those areas in which there was protection afforded by the animal tie-down. The unprotected areas such as eyelids, ears, nose, tail, and feet are obviously burned but not the marked charring effect as seen in other animals.

The lungs demonstrate focal areas of hemorrhage and are otherwise dark.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: Focal atelectasis associated with a marked congestion and other areas of alveolar duct distention bordering on emphysema are observed.

Eyes: Microscopic examination of the corneal epithelial cells demonstrate the presence of multiple black particles, presumably aluminum oxide, and a moderate edema of the interstitial fluid between the epithelial cells.

Skin: Third degree thermal burn characterized by necrosis of the skin down to the subcutaneous tissue is present.

Animal Number 129 (Continued)

Heart, Liver, Kidney, Spleen, GI Tract, and Testes: No significant abnormalities.

Photomicrographs of the corneal epithelium demonstrating the black particulate matter and the edema are taken.

Animal Number 140

Gross Examination:

The hair has been mainly shaved from the animal leaving behind certain areas of hair stubble in those regions difficult to shave. In the hair stubble there is an intense uniform burning producing charring of the hair and adjacent skin, however, those areas unprotected by hair fail to demonstrate any gross changes suggestive of an intense third degree thermal burn, but show multiple focal areas of hemorrhage, varying from 2 to 5 mm. in diameter. These are especially prominent in an area of shrapnel impact on the region of the left flank.

The lungs are focally hemorrhagic, but no other significant abnormalities of the viscera are observed.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: Congestion and a minimal pulmonary edema are associated with focal minimal pulmonary hemorrhage and a distantion of the alveolar ducts producing an early centrilobular emphysema.

Animal Number 140 (Continued)

Skin: Third degree thermal burns are present in those involved areas of the skin, but this does not extend into the deeper dermis as on previously burned animals.

Heart, Kidney, Spleen and Liver: No significant abnormalities.

No photomicrographs taken.

Animal Number 141

Gross Examination:

The animal is completely devoid of hair, having been depilated by Nair leaving a pink, somewhat mositened epidermis. No evidence of thermal burn is observed, but multiple focal areas of petechiae varying from 3 to 5 mm. underneath the skin are present. There is a moderate wound in the left flank which is the result of a shrapnel injury producing hemorrhage and destruction. A larger and more significant wound involves the left flank in which the defect produced measures 14 x 8 mm. and is surrounded by a ring of intense contusion measuring up to (the zone) 2 cm. in diameter, peripherally about the defect. The peritoneal cavity contains a moderate amount of blood and focal material and examination of the large bowel demonstrates several large everting traumatic wounds with spillage of intestinal contents. Smaller but similar everting bowel perforations are observed within the small bowel. Hemorrhage extends back into the para spinal muscles.

Animal Number 141 (Continued)

The lungs are grossly congested.

Gross photographs are taken of both the aminal and lungs.

Microscopic Examination:

Lungs: A mild congestion and small focal areas of atelectasis are observed.

Heart, Spleen, Kidney, and Liver: No significant abnormalities.

No photomicrographs taken.

Animal Number 142

Gross Examination:

The hair has been completely removed from the animal through use of a depilatory, Nair. There is no evidence of thermal burns, however, multiple small petechiae varying from 2 to 5 mm. in diameter are scattered about the moistened epidermal surface.

The lungs are grossly normal.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: A moderate focal atelectasis and congestion together with distention of the alveolar ducts bordering on a centrilobular emphysema is observed. In addition there is a concomitant peribronchial inflammatory response.

Skin: Sections of skin are improperly embedded, but show no evidence of thermal burn.

Animal Number 142 (Continued)

Heart, Kidney, Liver and Spleen: No significant abnormalities.

No photomicrographs taken.

Animal Number 144-145

Gross Examination:

The side represented as 144 presents a depilated surface which is moistened with several small focal areas of petechiae scattered about. No evidence of thermal burn is observed.

On the side labeled 145 there is a large shrapnel wound involving the right thigh with an associated hemorrhage and destruction of muscle.

The lungs are congested but no other visceral abnormalities are observed.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: Pulmonary congestion and edema of a moderate nature are observed with some centrilobular distention. Peribronchial inflammatory reaction is also associated.

Skin: Sections demonstrate an intense loss of epidermis with only a few superficial epidermal cells remaining. No evidence of hair is observed in the exposed portion of the skin, however, hair shafts still remain within the substance of the dermis.

Animal Number 144-145 (Continued)

Heart, Kidney, Spleen, Testes, and Liver: No significant abnormalities.

Photomicrographs are taken demonstrating the marked loss of surface epithelium due to the depilatory.

Animal Number 154

Gross Examination:

The hair is uniformly burned to the epidermis and structures not protected by the hair, such as the eyelids, ears, nose, tail, and feet demonstrate an intense charring effect. The eyes show an opacifying change within the cornea. Only those areas that were protected by animal tie-down show no evidence of burning. The tongue is burned. The lungs show evidence of hemorrhage but there is no other significant visceral change.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: A pulmonary congestion and moderate edema is observed with focal areas of hemorrhage.

Skin: Third degree thermal burns are observed down to the mid-dermis.

Heart, Liver, Spleen, Testes and Kidney: No significant abnormalities.

No photomicrographs are taken.

Animal Number 161

Gross Examination:

Although there is a moderate deposition of aluminum oxide particles about the hair and there are focal areas of singeing of the hair varying up to 12 mm. in diameter, other foci, especially in the left flank region shows an area of hemorrhage.

Lungs are grossly normal as are other viscera.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: A moderate pulmonary edema and congestion are present.

Heart, Liver, Spleen, Testes and Kidney: No significant abnormalities.

No photomicrographs are taken.

Animal Number 162

Gross Examination:

Over the region of the left shoulder and back there is a moderate aluminum oxide particle deposition and in association there is a slight superficial singeing of the hair.

The lungs and other viscera are normal grossly.

Gross photographs are taken of both the animal and lungs.

Microscopic Examination:

Lungs: A moderate bronchopneumonia with congestion and edema are present.

Animal Number 162 (Continued)

Kidney, Heart, Liver and Spleen: No significant abnormalities.

No photomicrographs are taken.

Animal Number PC

Gross Examination:

The animal demonstrated no abnormalities on external or internal examination.

Microscopic Examination:

Lungs: A minimal congestion is present together with a mild distention of the alveolar ducts.

Heart, Kidney, Liver and Spleen: No significant abnormalities.

No photomicrographs are taken.

APPENDIX 'B'
INSTRUMENTATION

INSTRUMENTATION

It was attempted in each test to record: pellet velocity and light intensity, cabin pressure vs. time, flash temperature vs. time, and blast pressure vs. time. The following instrumentation provided the means for recording this data.

Particle Velocity & Light Intensity - Five TI-1N2175 photodiodes were used in the instrumentation of the test. One diode was positioned above the shaped charge to record the detonation time and consequently the instant of initial particle acceleration. Three diodes were placed inside the cabin chamber, facing the target plate, to record the light produced by penetration of the target. These, more or less, surrounded the test specimen, looking back at the flash. On tests in which a screen was placed on the charge side of the target, an additional diode was positioned to face the screen. The diode positioned near the charge triggers a horizontal sweep across the scope of the Hughes 104 Memoscope. The other diodes, when stimulated, cause a vertical deflection on the scope, proportional to the intensity of the light sensed. The scope thus presents light intensity vs. time. The distance travelled by the pellet is known therefore making possible the calibration of particle velocity in feet per second.

In addition, the signal producing the vertical deflection on the scope was fed through a Kintel Model 111 BF Amplifier to a galvonometer in a C.E.C. Model 114 Recording Oscillograph.* This deflection produced a penetration time zero to which other recorded phenomena could be referenced on the oscillograph record.

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*For the last 44 tests, the C.E.C. Model 114 Oscillograph was replaced with a Minneapolis Honeywell Visicorder. This enabled readout of data immediately after a test.

Vertical deflection of the memoscope was, in each test, previously calibrated to provide light intensity in foot candles. A calibration curve was obtained by measuring the current flowing through the photodiodes for known light intensities. A Sylvania Sun Gun was used as a light source, and the light sensed by the diodes was measured with a Wollensak Light Meter. Consequently, the light intensities recorded are relative to these items.

Filters were used interchangeably requiring recalibration of the light deflection curve. These filters were: Kodak Wratten 301 infrared rejection, 78B Visual photometric, and a "B" glass ultra violet rejection.

Blast Pressure vs. Time - A Endevco Model 2501 piezoelectric pressure transducer, was located flush with the platform on which the animal was positioned. The transducer was wired to an Endevco cathode follower. Power was supplied by a Lambda Model C-281 power supply. The signal produced was fed through a Kintel Model 111 MF amplifier to a C.E.C. Type 7-316 galvonometer. The current was measured and recorded on a C.E.C. model 11A recording Oscillograph. The signal from the cathode follower was also fed into a Hughes 10A Memoscope. The memoscope was used in conjunction with the Oscillograph since the galvanometer does not have high enough response rate to give accurate data. The cathode follower is desirable in presenting a high impedence load with a low shunt capacitance to the transducer. The range of the transducer is 0-500 P.S.I. with a nominal output of 58 millivolts per P.S.I. The response time is 5 microseconds (0-90%).

To Record Cabin Pressure vs. Time - A C.E.C. Type 4-312 pressure transducer, with a range of from 0 to 25 PSIA was installed in the cabin chamber. The transducer was connected to a BAM-1 which supplied excitation voltage to the transducer and amplified the transducer output. The BAM output was fed into a 7-318 galvanometer and recorded on a C.E.C.

model 114 recording oscillograph.

To Record Flash Temperature vs. Time - A Baldwin-Lima-Hamilton - Thermocouple, Type TCA-ES-50, with an ice bath for reference, was used to detect changes in temperature within the cabin chamber. The signal was fed through a Kintel amplifier to a 7-318 galvanometer and was recorded on the oscillograph. The thermocouple above was found to be the best for this purpose; however, an accurate recording was not anticipated since the response time of thermocouples, or any other temperature sensor, is generally too great when used in air. At 350°F the time constant is 13 milliseconds.

Camera Recordings - A Fastax 16 mm motion picture camera was located above the cabin chamber to record, through a window, the effects inside the cabin chamber during and immediately after penetration. A transformer, "The Goose" by Wallensak, was used to increase the voltage supplied to the camera. The camera without the Goose had a speed of 2800 frames per second. By increasing the voltage, the speed was stepped up to 6000 frames per second.

A Polaroid camera was used to record the deflections on the face of the Memoscope. These photographs were filed with the test records for each shot. The Polariod camera was used also to record the particle stream and energy release of the particles penetrating the target plate. The shutter of the camera was left open and the light produced upon penetration was the source of illumination to the camera.

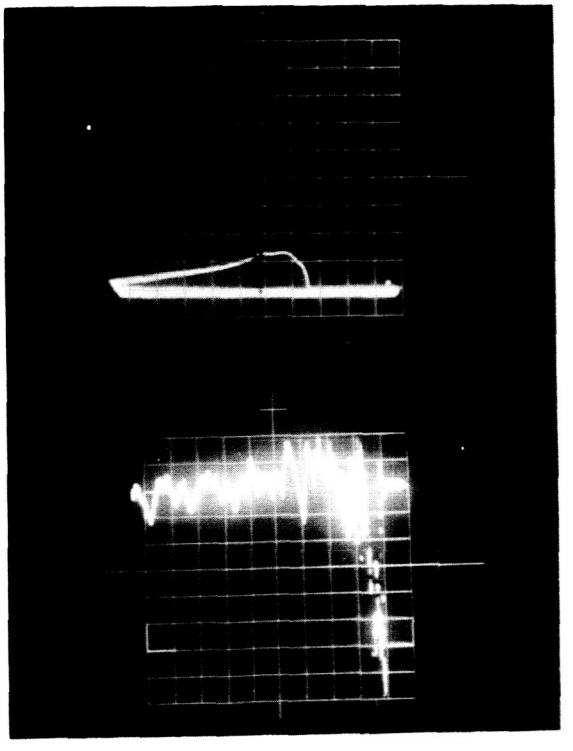

FIGURE B-1. POLAROID RECORD OF LIGHT INTENSITY (TOP) AND BLAST PRESSURE (BOTTOM) DEFLECTIONS ON FACE OF HUGHES MEMOSCOPE

APPENDIX 'C'
SUMMARY OF TESTS

TEST FIRING RECORD -- CABIN ATMOSPHERE MICROMETEORITE PENETRATION PROGRAM

All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

EWA 2006
FO 3-45150
Contract No. NASw-416

No.	Purpose	Pellet Diameter x Thick	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total Inches	Gross Effect on Animal Specimen	Comment and Camera Results
1 - 6	Instrumentation and facility checkout	0.1" x 0.006, Ti	0.16", 7075T6 Al	@23,000	- - - -	- - - -	@0.005/20	None Used	Additional instrumentation found to be required. Adequate data obtained, however, to proceed with preliminary test firings.
7	Control test firing to determine adequacy of epoxy resin to fix pellet to shape charge so as to obtain maximum contact period between pellet and blast wave after detonation	0.1" x 0.002 layer Epon 828 dried 24 hours	0.16", 7075T6 Al	- - - -	- - - -	- - - -	No Penetration	None Used	Epoxy pellet did not penetrate target or cause significant deformation; therefore, was selected to fix pellet to charge.
8 - 70	Series of test firings to select the proper grit size, thickness, shape charge configuration and thickness of bonding material to obtain optimum velocity using SiC as pellet material	20, 40, 60, and 70 grit SiC in various layer thickness and amounts of epoxy	0.16", 7075T6 Al	22,000	800	3.0	Varied with grit size and thickness	None Used	Finally obtained velocity by increasing size of shape charge and bonding the SiC in as thin a layer as possible and using a uniform distribution of 40 to 60 grit. Fixing the SiC in molten glass also provided good velocities but is inconsistent in performance.
71	Two test firings through titanium targets to observe results	60 grit SiC set in Epon 828 on shape charge 0.1" x 0.05"	0.020 Ti(#4901)	22,700	300	low	@0.03/5	None Used	Very small and very few penetrations
72	Second test of Ti Target	60 grit SiC set in Epon 828 on shape charge 0.1" x 0.05"	0.012 Ti(#4901)	28,700	1500 (off scale)	3*	@0.04/40	None Used	Instrumentation response off scale. Polaroid photograph indicates high light energy release much greater than with Al targets.
73**	First animal test firing using SiC grit in epoxy resin to investigate animal response to lower energy release levels. 100% O_2, 5 psia in cabin chamber	As above	0.16", 7075T6 Al	27,900	1050	5*	@0.03/50	Adult white rat, 300 gm, showed mild shock only, with good response to visual, noise, and touch stimuli.	Rat located 1" below and 2 1/2" out from target. Pressure pickup immediately in front of rat. (See attached sketch.)

* All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total	Gross Effect on Animal Specimen	Comment and Camera Results
74	Repeat of above 100% O_2, 5 psia in cabin chamber	60 grit SiC set in Epon 828 on shape charge 0.1" x 0.05"	0.16", 7075T6 Al	26,400	625	5*	Inches @0.03/100	Adult white rat, 300 gm, showed mild shock only, with good response to visual, noise and touch stimuli.	Rat located 1" below and 2 1/2" out from target. Pressure pick-up immediately in front of rat. (See attached sketch.)
75	As above, cabin atmosphere; 100% O_2, 5 psia	As above	As above	23,800	850	5*	@0.03/75	As above, with slight nose bleed, probably due to accidental vacuum pump reversal during test preparation	As above. Fastex camera used. Motion picture film indicated flash produced, but unable to determine if animal reached by primary energy release.
76	As above, cabin atmosphere: 100% O_2, 5 psia	As above	As above	27,500	500	5*		As above	As above. Fastex camera used. Little rat response was seen and light was of small size. Penetrating particles were seen to pass over rat.
77	Evaluate a thin glass pellet to try to obtain greater energy release. Cabin atmosphere: 100% O_2, 5 psia	0.1" x 0.007" glass	0.16", 7075T6 Al	36,000	600	5*	@0.04/22	Slight singeing of a few tips of fur. Perhaps a little indication of increased shock and flash blindness.	Polaroid camera confirms small light (flash) production. Results surprising in view of the high velocity achieved.
78	Test firing to study glass pellet in conjunction with 100% O_2 at 11.7 psia. Cabin atmosphere	As above	As above	27,900	1500 (off scale)	5*	@0.09/21	Slight singeing of fur tips again. Rat appeared unable to detect visual stimuli.	Polaroid camera failed. Relationship between O_2 concentration and energy release noted. Target material displacement was also increased, however, by concentration of impacting particles.

*All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total Inches	Gross Effect on Animal Specimen	Comment and Camera Results
79	Test firing to study glass pellet in conjunction with 100% O_2 at 14.7 psia. Cabin atmosphere	0.1" x 0.007" glass	0.16", 7075T6 Al	28,500	1500 (off scale)	3*	@0.12/25	Flash blindness indicated by lack of visual response. No other symptoms other than some shock.	Polaroid film confirms increased light energy release.
80	Changed back to SiC pellet to evaluate energy release of SiC pellet in 100% O_2 at 14.7 psia.	0.1" x 0.05" SiC in epoxy	As Above	21,700	3000* (scale increased on recorder)	2*	@0.05/100	No adverse effect noted.	Polaroid camera does not verify light intensity level recorded. Change in scale probably changed calibration.
81	Returned to use of glass pellet. Cabin atmosphere: 100% O_2, 14.7 psia	0.1" x 0.007" glass	0.16, 7075T6 Al	31,300	3000*	2*	@0.05/30	Slight hair singeing.	Instrumentation probably off scale on light.
82	Recalibration of instrumentation attempted using rat in cabin chamber under atmospheric conditions	As above	As above	- - - -	- - - -	- - - -	- - - -	Appeared in shock.	Instrument leads not attached properly.
83	Test of recalibrated instrumentation. Cabin atmosphere: 100% O_2, 14.7 psia	As above	As above	31,200	7500	3*	@0.18/25	Slight singeing of hair tips. In shock with reduced visual response.	Fastex film data verified light intensity.
84	Test firing of a larger diameter glass pellet. Cabin atmosphere: 100% O_2, 14.7 psia	0.24" x 0.007" glass	As above	30,000	7500	10* (off scale)	@0.14/150	Little effect noted, but animal off platform.	Fastex camera verified light flash and showed increase in penetrating particle stream. Particles seen as patches of burning materials moving at great speed.
85	As above. Cabin atmosphere: 100% O_2, 14.7 psia	0.24" x 007" glass	As above	29,400	22,500 (off scale)	10 (off scale)	0.50/150	Shock produced animal very disoriented. Slightly singed.	Greatest energy release thus far obtained.

* All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick.	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total Inches	Gross Effect on Animal Specimen	Comment and Camera Results
86	Having noted increased energy release directly related to amount of metal displaced from cabin wall, switched to thicker wall material. Available material had been pressed into hemispherical shape. Must have higher energy release to burn rat. Cabin atmosphere: 100% O_2, 14.7 psia	0.24" x 0.007" glass	0.064", 5052SO Al	30,200	22,500 (off scale)	2*	0.375/6	Singed and in shock.	Although tremendous energy release obtained, verified by Fastex film data, the rat did not burn. Rats in all previous tests located below line of impacting particles.
87	Moved rat into line of travel of penetrating particles. Cabin atmosphere: 100% O_2, 14.7 psia	As Above	As Above	29,400	High (off scale)	13*	.37/10	Animal uniformly burned to epidermis.	Fastex film indicated violent and immediate burning. All instrumentation destroyed by fire.
88	Instrumentation check-out. Shape charge fired to determine if penetration required for light energy release (thought possible ionization phenomenon). Cabin atmosphere: atmospheric pressure and concentration of O_2	None	As Above	None	None	None	None	None Used	Polaroid film showed no light produced.
89	Verification of test #87. Cabin atmosphere: 100% O_2, 14.7 psia. Instrumentation checkout	0.24" x .007" glass	As Above	30,700	50,000	7*	.022/9	Animal burned uniformly to epidermis.	Fastex film data verified early result. Much smaller hole in cabin wall than in test #87.
90	Cabin atmosphere: 100% O_2, 5 psia	0.24" x 0.007" glass	0.064", 5062So Al	31,300	22,500	4*	0.06/4	Burned uniformly to depth of hair, but ears and lips not burned. Animal not dead on removal from cabin chamber.	Detectable relationship noted between O_2 concentration and degree of burning of rat. Small amount of wall material displaced in this test firing.

* All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick.	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total Inches	Gross Effect on Animal Specimen	Comment and Camera Results
91	Cabin atmosphere: 100% O_2, 5 psia	0.24" x 0.007" glass	0.064", 5052SO Al	None	None	None	None	None	No penetration of target. Cause unknown.
92	As Above	As Above	As Above	33,400	60,000 (off scale)	14*	0.3/4	Burned uniformly as in test #90	Same as test #90
93	As Above	As Above	As Above	33,400	9,000	14*	0 18/6	Did not burn. Injury to left shoulder due to impact. Appeared in shock.	Low light intensity only clue to why burning did not occur. Polaroid indicates little light produced.
94	As Above	As Above	As Above	27,800	60,000 (off scale)	14*	0.5/4	Burned as in tests #90 and 92	Large hole produced 0.5 x 0.25 inches. Burning appeared normal. Polaroid overexposed.
95	Attempted to return to 60 grit SiC for test with rat in line of particle travel. Cabin atmosphere: 100% O_2, 5 psia	0.25" x .05" SiC 60 grit	As Above	None	None	None	None	None	No penetration of wall achieved.
96	Cabin atmosphere: 100% O_2, 3.5 psia	0.25" x .007"glass	0.064", 5052SO Al	29,400	2,000	None	0.12/2	None	Very low light level and little penetration.
97	Attempted to return to 0.1 dia. glass pellet with rat in line of particle penetration. Cabin atmosphere: 100% O_2, 5 psia	0.1" x .007" glass	As Above	None	None	None	None	None	No penetrations of wall achieved. Fastex camera used.
98	Went to thinner cabin wall material and 0.1 dia. glass pellet. Cabin atmosphere: 100% O_2, 5 psia	0.1" x .007" glass	0.020", 5052SO Al	35,800	3,700	5*	0.06/7	Heavy singeing, shock.	Amount of wall metal displaced was very small and light intensity. Fastex camera used.
99	As above. Cabin atmosphere: 100% O_2, 5 psia	As Above	As Above	31,200	24,800	6*	0.25/20	Uniform burning as in other 5 psia O_2 tested.	Concentration of penetrating particles in a line resulted in hole 0.18" x 0.25" being made in wall. Fastex.
100	Returned to thicker targets. Cabin atmosphere: 100% O_2, 5psia	0.25" x .007" glass	0.064", 5052SO Al	28,200	22,500 (off scale)	4*	0.18/11	Uniform burning as above.	Verification test. Fastex camera used.

*All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick.	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total Inches	Gross Effect on Animal Specimen	Comment and Camera Results
101	Cabin atmosphere: 100% O_2, 3.5 psia	0.25" x .007" glass	0.064", 5052S0 Al	34,500	22,500	4*	0.37/3	Burned uniformly leaving hair length .15" to .2" long.	Burning obviously oxygen limited. Particles concentrated for large hole .15" x .375" Fastex camera used.
102	Again attempted to use thin target and small diameter pellet so as to obtain burning with smallest possible particles. Cabin atmosphere: 100% O_2, 5 psia	0.1" x .007" glass	0.020", 5052S0 Al	37,100	2,000	4*	0.06/35	No burning, shock	Low light intensity, little wall material displaced. Fastex camera used.
103	As above	As above	As above	28,700	450	None	0.06/28	None	As above
104	As above	As above	As above	34,400	2,000	1*	0.06/16	None	As above, except Polaroid camera used.
105 & 106	Test made to check an addition to test setup designed to seal off firing chamber to prevent repressurization to atmosphere pressure after firing. Such was required to maintain the firing chamber negative to the cabin chamber so that the decompression would be constant in the latter.	As above	As above	34,500	6,000	10*	0.08/15	None Used	Apparatus worked. Record maintained on cabin pressure.
107	Returned to test program. Cabin atmosphere: 100% O_2, 3.5 psia. Large pellet and thin target used on remaining tests.	0.23" x .006" glass	As Above	- - - -	- - - -	13*	0.4/20	Animal burned as in test #101.	Instrumentation failure. Polaroid film overexposed.
108	Cabin atmosphere: 380 mm O_2, 7 psia	As above	As above	27,800	22,500 (off scale)	18*	0.5/45	Animal in shock, wounds in shoulder. Did not burn but singed heavily.	Inadvertently established wrong O_2 partial pressure. Fastex camera used.
109	Cabin atmosphere: 380 mm O_2, 7 psia	0.23" x .006" glass	0.020", 5052S0 Al	29,400	22,500	19*	0.5/55	Animal burned uniformly with some hair left.	Note above. Got very large penetration of cabin wall and much metal displaced. New light filters on order. Fastex camera used.

TEST FIRING RECORD - CABIN ATMOSPHERE MICROMETEORITE PENETRATION PROGRAM (continued)

* All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick.	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total Inches	Gross Effect on Animal Specimen	Comment and Camera Results
110	Cabin atmosphere: 380 mm O_2, 7 psia	0.23" x .006" glass	0.020", 5052S0 Al	- - -	22,500 (off scale)	20*	0.25/35	Animal burned uniformly with some hair left.	Note above. Got very large penetration of cabin wall and much metal displaced. New light filters on order. Fastex camera used.
111	Cabin atmosphere: 180 mm O_2, 7 psia	As above	As above	- - -	22,500 (off scale)	12*	1.25/50	Heavily singed, in shock.	Interconnecting penetrating particles made hole 1.25" x 0.15". Fastex camera used.
112	As Above	As Above	As Above	High	High	16*	0.5/20	Approximately 3 sq. in. singed very heavily.	As above. Instrumentation problems continue. Fastex camera used.
113	As Above	As Above	As Above	High	High	High	0.4/40	Approximately 2 sq. in. singed	As above. Fastex camera used.
114	As above	As Above	As Above	28,000	157,000	- - -	0.7/25	As above	Instrumentation back in operation. Fastex camera used to backup instrumentation.
115	As Above	As Above	As Above	27,800	62,000	- - -	1.2/30	As above	Polaroid overexposed, more filters added.
116	As above	As Above	As Above	27,800	20,000	14*	0.25/100	Some singeing and shock	Polaroid good.
117	Cabin Atmosphere: atmospheric	0.23" x .006" glass	0.020", 5052S0 Al	27,500	48,000	17*	1.5/20	Hair singed over 1" wide path along line of particle travel.	Polaroid again nearly overexposed.
118	As Above	As Above	As Above	30,000	50,000	24*	1.5/70	As above	As above
119	As above	As Above	As Above	31,300	80,000	36*	1.0/30	As above	Believe finally got pressure recording system functioning properly. Fastex results good.

* All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick.	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max. Dia./Total	Gross Effect on Animal Specimen	Comment and Camera Results
							Inches		
	Start of 2 cu. ft. Cabin Chamber Test Series								
120	Cabin atmosphere: 100% O_2, 3.5 psia	0.23" x .006" glass	0.020", 5052SO Al	26,300	200,000	28*	1.0/50	One-fourth of the rats fur was burned off uniformly over the animal. Animal was very much alive when brought out of chamber.	Fastex film data verifies that rat burned out in approximately 0.3 sec. Oxygen reduced below 3.5 psi by decompression to the firing chamber.
121	As above	As above	As above	27,000	65,000	28*	1.0/75	As above	Polaroid overexposed. Used temperature sensitive paint. Results indicated temperature between 225°F and 950°F. Thermocouple too slow in response for the transient heat obtained.
122	Cabin atmosphere: 180 mm O_2, 7 psia	0.23" x 0.006" glass	0.020", 5052SO Al	27,800	80,000	9*	1.0/30	Severe localized singeing. Some shock. No visual response.	Polaroid nearly overexposed, but good data on flash size.
123	As above	As above	As above	27,800	63,000	18*	1.2/20	Area 1.5" dia. denuded of hair by singeing.	Polaroid data poor.
124	As above	As above	As above	27,700	75,000	17*	0.7/50	Localized singeing.	Polaroid failure.
125	As above	As above	As above	27,700	58,000	19*	0.4/30	As above, but singeing on side of rat away from target wall of cabin	Polaroid indicates broad area of energy release, although only one major hole made in wall. Flash must wrap around or envelop rat because of singeing on side opposite penetration.
126	As above	As above	As above	27,800	50,000	29.5	0.7/25	Singeing again seen in streaks with AlO deposits on edge of path.	Fastex film data good.

* All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick.	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total Inches	Gross Effect on Animal Specimen	Comment and Camera Results
127	Cabin atmosphere: atmospheric O_2 and pressure	As above	As above	27,300	65,000	38	2.0/20	Very broad singeing but not heavy or deep.	Very large amount of wall material displaced. Highest blast pressure thus far recorded. Believe to be accurate. Pressure rise and fall seen to occur in 0.025-0.050 sec. in all tests. Fastex film good.
128	Epoxy control repeated for 0.25 pellet size with three day curing time	0.24" x .001" Epon 828	0.020", 5052S0 Al	- - - -	- - - -	- - - -	None	None	Trying to account for large holes made in target by a maximum 2000 pellet. Test indicated not related to epoxy control.
129	Repeat of 3.5 psia, 100% O_2 test	0.24" x .006" glass	As Above	32,300	125,000	31	0.5/75	Animal burned uniformly. Only 25% of fur length consumed.	Color Fastex used successfully to get brightness and color information regarding burning.
130	Cabin atmosphere: atmospheric O_2 and pressure	As above	As above	29,400	15,000	30	0.25/60	Singeing confined to impact area on rat. Animal hit heavily.	Polaroid data good.
131	As above	As above	As above	28,500	33,000	32	1.3/75	General singeing.	As above
132	As above	As above	As above	31,000	33,000	34	0.5/75	As above	As above
133	As above	As above	As above	- - - -	- - - -	- - - -	1.0/30	Area 0.5" dia. denuded by singeing.	Polaroid data good. Large amount of wall material displaced by penetrating particles.
134	Repeat of 5 psi 100% O_2	0.23" x .0064	.020, 5052S0	30,100	115,000	Failed	1.0/50	Hair singed heavily and broadly, shock. Blind and deaf.	Should have burned rat. Recheck required.
135	Repeat of above to determine cause of failure to burn.	As Above	As Above	28,600	80,000	11	.6/50	As Above	No camera used. Seeking cause rat did not burn.

*All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick.	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total	Gross Effect on Animal Specimen	Comment and Camera Results
136	Repeat of above to determine cause of failure to burn.	As above	.020, 5052	31,000	60,000	28	.3/75	Hair singed heavily and broadly, shock, blind,deaf	Fastex with goose.
137	As above	As above	As above	31,000	60,000	28	.3/60	As above	No camera used.
138	As above	Si O_2	As above						Inadequate flushing produced diluted oxygen. Analyzer read 100% O_2 when actually was about 80%. This may be reason rats did not burn. No camera.
139	5 psi in cabin chamber 100% O_2 with surge chamber	.23 x .0054 glass	As above	34,500	60,000	23	.17/150	Animal burned uniformly. Third degree burns to skin.	No camera used.
140	5 psi in cabin chamber 100% O_2 without surge chamber. Used shaved rat.	As above	As above	29,400	150,000	12	.4/75	Areas with hair on burned. Injury from spalling.	Hair not completely removed by shaving so rat burned. Used Fastax with Goose. Appears to be smoke and flame in the area of impact.
141	5 psi in cabin chamber 100% O_2 with surge chamber used naked rat (Nair)	As above	As above	did not trigger	65,000	12	.4/100	No evidence of thermal burn. Large wound from particle penetration animals intestine.	Rats hair was completely removed. Used Fastax with Goose. Results as above.
142	As above	As above	.020, 5052S	29,600	90,000	20	1.0/50	Usual freckled skin. No injuries and no burning	Major penetration particles went under the rat. Fastax was used. Results as above.
143	5 psi, 100% O_2 with flat target and normal rat	As above	.016, 7075 T6 Aluminum	31,700	275,000	30	/75	Animal was in particle stream and burning occurred with usual pathological results.	Fastax was used.
144	Glass pellet used, 100% O_2, 14.7 psi and nude rat	.23 x .0054 glass	.020, 5052S	30,800	75,000	9	.2/100	Usual freckles from spalling. No thermal burn.	Fastax used. Smoke and flame appear to be present in area of impact.
145	As above	As above	As above	30,800	200,000	36	.7/75	As above	As above

*All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick.	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total	Gross Effect on Animal Specimen	Comment and Camera Results
146	Back to 5 psi 100% O_2 cabin pressure with 0.25 Al screen plate having (4) 3/8" dia. holes	.23 x .0054 glass	.020, 5052S	33,300	None	None	None	No significant injury.	No light produced since there were no penetrations. No film data.
147	Using particle screen and surge tank. 100% O_2 - 5 psi cabin pressure	As above	As above	28,600	Too low to trigger	None	.02/2	As above	Few penetrations, as above.
148	As above	As above	As above	31,300	None	- - -	None	As above	As above
149	Using screen without surge chamber - cabin pressure 100% O_2 - 14.7 psi	As above	As above	33,300	No trigger	Not being measured	None	As above	As above
150	As above	As above	As above	35,200	Did not trigger	Not measured	None	As above	As above
151	As above			31,800	No trigger	- - - -	.02/1	As above	As above
152	1st shot with test room heater. Cabin pressure 100% O_2 - 5 psi modified strainer (4) 1/2" holes with center hole 3/8" diameter.	.23 x .0054 glass	.064 x 5052 Al	31,300	None	None	None	No significant injury	As above
153	As above	As above	.064 x 5052S	30,000	None	None	None	As above	As above
154	As above	As above	As above	30,300	25,000 (off scale)	Not recorded	.3/1	Uniform burning of hair and third degree thermal burns of skin.	Large penetration was caused by particle passing directly through screen hole. Cri jaws failed causing rapid depressurization.
155	As above	As above	As above	31,300	None	None	None	No significant injury	No penetration, no light available. Fastax used.
156	As above	As above	As above	34,500	None	None	None	As above	Fastax used. No light available to record.

*All tests conducted at a firing chamber pressure of 4 Hg or less. Tests #1-119 in 4 cu. ft. chamber; #119-123 in 2 cu. ft.

No.	Purpose	Pellet Diameter x Thick.	Cabin Chamber Wall Material	Velocity ft/sec	Light Intensity (ft.cdls)	Blast Pressure (PSIA)	Penetration Max.Dia./Total	Gross Effect on Animal Specimen	Comment and Camera Results
157	1st shot with test room heater. Cabin pressure 100% O_2 - 5 psi modified strainer (4) 1/2" holes with center hole 3/8" diameter	.23 x 0054 glass	.064, 5052S		None	None	None	No significant injury	Fastax used. No light available to record.
158	As above	As above	As above	33,300	None	None	None	As above	As above
159	As above	As above	As above	33,300	None	None	1 Spall	As above	As above
160	As above	As above	.020, 5052 Al	32,300	Too low to trigger	Not recorded	.02 Dia. 3 inter-locking 3 separate	Deposit on left hind quarter. Animal was blinded.	Light available was low.
161	As above	As above	As above	31,000	2,750		.07/4 widely spaced	Slight singeing and aluminum oxide deposits	As above
162	As above	As above	As above	31,000	Below detection threshold		.01/1	As above	As above
163	As above	.25 x .0054	.020, 5052	30,300	22,500		.1/2 (1) very small	As above although direct hit was made.	Good Fastex
164	As above	As above	As above	33,000	Below threshold		.01/2	No significant injury	Very low light available.
165	As above	As above	As above	32,000	As above		.01/1	As above. Appears to be in shock.	As above
166	Testing .020" thick titanium target	As above	.020 Ti-4901	32,000	None	None	None	No significant injury.	As above
167	As Above	As above	As above	30,300	5,500		.05/1	Slight singe and shock symptoms.	As above.

APPENDIX 'D'
ADDITIONAL PHYSICAL RELATIONSHIPS PREDICTED BY TEST DATA

D-1. DISCUSSION

Distribution of animal specimen response is indicated on a plot of: light produced by particle penetration of the target wall vs. total wall area displaced. Target thickness, pellet size, and the test atmosphere are also indicated for each test shown. Animal response information is limited to an indication of burning or non-burning.

As can be seen (Figure D-1), the points indicating tests in which specimens were burned are fairly well separated into two groups according to target wall thickness. Total hole area sizes and light intensity levels, which caused specimen burning in tests using the 0.064 inch thick target, do not produce fires in tests using the 0.020 inch thick target. All but one of the tests which produced burning used the 0.24 inch diameter pellet. Total hole areas displaced in the two targets were thus fixed by the physical factors controlling the potential for penetration of a given hypervelocity particle through a given wall thickness. Using the equations developed by Palmer (Reference 3) the particle (or particles) which could displace these hole areas can be identified for various particle velocities. The amount of wall area which will be displaced can also be predicted.

The data presented is useful for two purposes. First, they substantiate the relationships described in this report between oxidative energy release level and the amount of target wall material displaced; the latter being much more determinant than oxygen concentration. Also light intensity level is again identified as a good indicator of the level of energy release and can be used to predict the degree of injury response.

The fact that a larger total wall area displacement is indicated to be required to produce injury or death behind a thinner (0.020 inch) wall rather than a thicker (0.064 inch) wall is worthy of note.

NOTE: 1. ALL HOLE AREAS GREATER THAN .030 SQ. IN. FROM .24" DIA. GLASS

2. ASSUMED VALUES WHERE NO DATA AVAILABLE

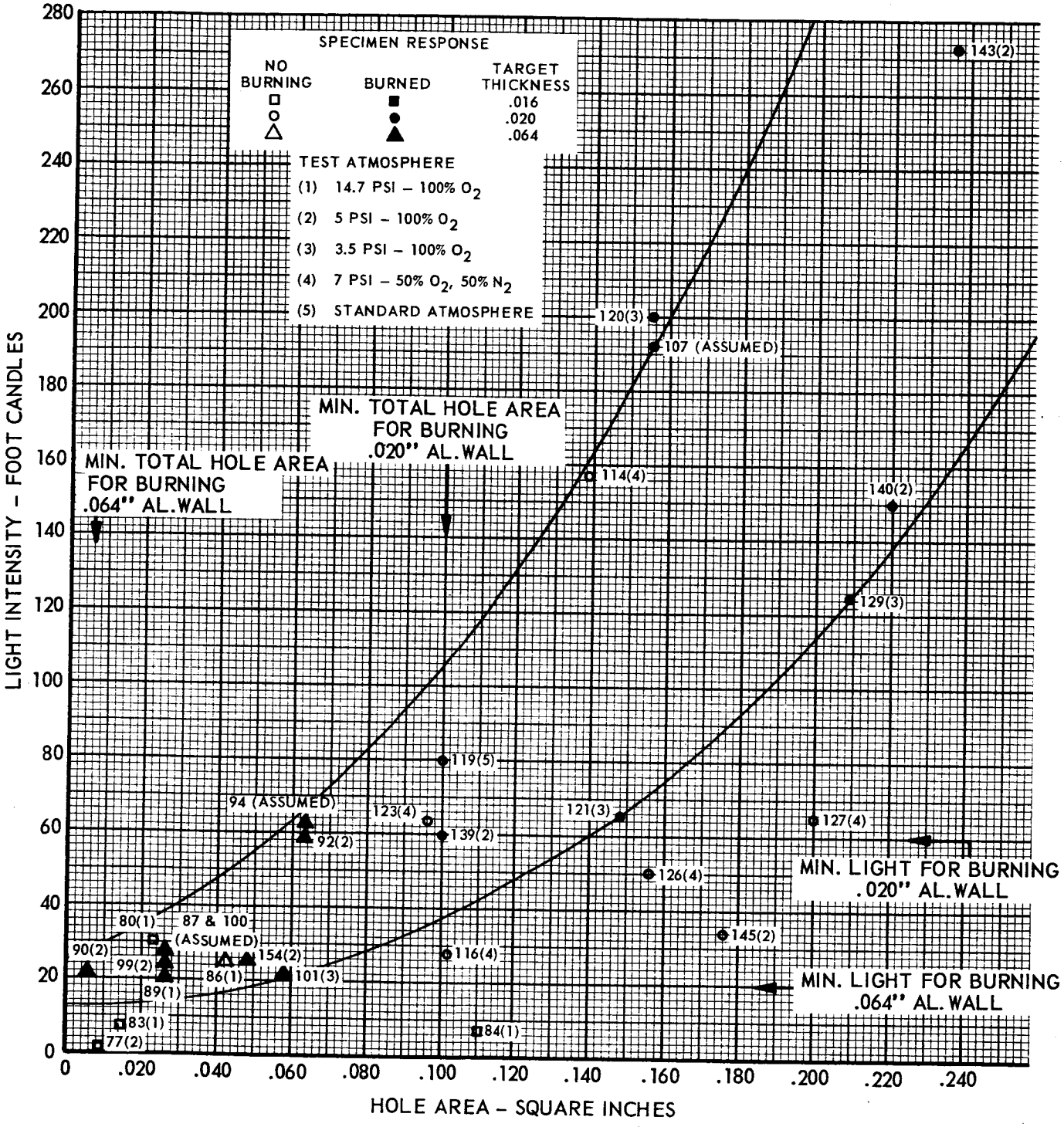

FIGURE D–1. SPECIMEN RESPONSE ON A PLOT OF HOLE SIZE VS LIGHT PRODUCED

GLOSSARY

Bronchopneumonia -- A name given to an inflammation of the lungs which usually begins in the terminal bronchioles (microscopic tubes of lung). These become clogged with an exudate forming consolidated patches in adjacent lobules.

Corneal -- Pertaining to the cornea - The transparent structure forming the anterior part of the external layer of the eyeball.

Depilate -- To remove the hair from.

Edema -- The presence of abnormally large amounts of fluid in the intercellular tissue spaces of the body.

Epidermis -- The outermost and nonvascular layer of the skin.

Hair Follicle -- The depression from which each hair grows.

Scrotum -- The pouch which contains the testicles and their accessory organs.